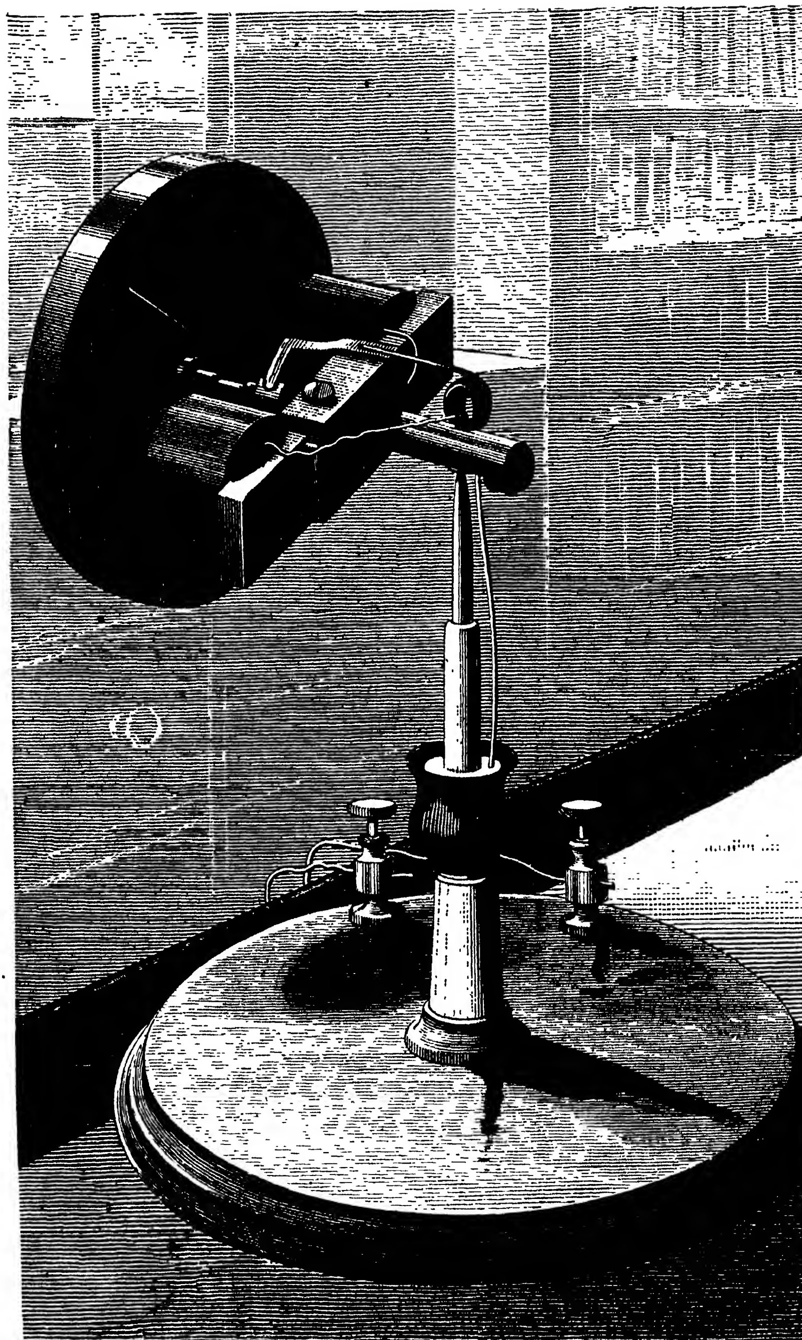
PLATE I



An Electrical Gyroscope.

EXPERIMENTAL SCIENCE.

ELEMENTARY

PRACTICAL AND EXPERIMENTAL

PHYSICS.

BY

GEORGE M. HOPKINS.

VOL. I.

TWENTY-THIRD EDITION

(REVISED AND ENLARGED)

NEW YORK:
MUNN & CO.

LONDON:
E. & F. N. SPON, LTD.
125 STRAND.

1902.

Macgowan & Slipper, Printers, 30 Beekman St., New York.

PREFACE.

THE design of this work is to afford to the student, the artisan, the mechanic, and in fact all who are interested in science, whether young or advanced in years, a ready means of acquiring a general knowledge of physics by the experimental method. One of its principal purposes is, also, to furnish to the teacher suggestions in experimentation, which will be helpful in making class-room work interesting and attractive, rather than dry and monotonous.

Most of the apparatus here illustrated and described may be constructed and used by any one having ordinary mechanical skill. Simple and easily made devices have been chosen for physical demonstration.

With scarcely an exception the experiments described were performed at the time of writing, to insure fullness of detail, and to avoid inaccuracies. The reader can therefore be assured that by following the instructions, success will be certain.

Mathematics has been almost entirely excluded. The few problems presented are capable of arithmetical solution. The importance of mathematical knowledge in all branches of science is fully recognized, but the majority of students have little taste for the intricacies of numbers. Faraday was an illustrious example of a scientific man without great mathematical proclivities.

The late Clerk Maxwell, one of the most eminent mathematicians and electricians of the present century, said: "A few experiments performed by himself will give the student a more intelligent interest in the subject, and will give him a more lively faith in the exactness and uniformity of nature, and in the inaccuracy and uncertainty of our observations, than any reading of books, or even witnessing elaborate experiments performed by professed men of science."

A large proportion of the material of this work consists of original articles published from time to time in the *Scientific American.* These have been revised or re-written, with copious additions of text and engravings. Very few of the conventional illustrations of the text books have been used. Most of the engravings are now for the first time given in book illustration.

The leading principles of physics are here illustrated by simple and inexpensive experiments. The endeavor has been to make the explanations of both apparatus and experiment plain and easily understood.

If what is here written shall induce any who are now indifferent to the subject to begin the study of physics experimentally, so as to gain even a faint conception of the marvelous perfection of the physical world, or if anything in these pages proves helpful to those who instruct, or who seek scientific information, the end sought by the writer will have been gained.

GEORGE M. HOPKINS.

NEW YORK, January, 1890.

PREFACE TO EDITION OF 1898.

THE seventeenth edition of Experimental Science contained an appendix including much new matter, but, in the four years which have elapsed since the publication of this edition, several startling physical discoveries have been made, among which are the X-Ray and its phenomena, Wireless Telegraphy, the Liquefaction of Air, and Acetylene Gas. These have been included in the present edition. Besides these, a number of additional experiments are given, some of which are new and original. The book has been considerably enlarged by the additions, and it has been revised so that it is in accord with recent ideas of the subjects treated.

The new matter added will prove acceptable to such as seek information on the more recent scientific discoveries.

GEORGE M. HOPKINS.

September 7, 1898.

PREFACE TO THE TWENTY-THIRD EDITION

IN order to broaden the scope of this work, the author has relaxed the rather rigid rule heretofore adhered to, which called for the trial by himself of every piece of apparatus described in its pages, and has now availed himself of the experience of others. He is therefore able to present to the readers of the twenty-third edition, a full explanation of the Polyphase Generator, Induction Motors, and Rotary Transformers, also to give accurate information regarding the construction of modern direct current motors for 110 volts pressure.

A full description of Edison's New Storage Battery is introduced, also some interesting experiments by Prof. John Trowbridge, and some Electrical Measuring Apparatus by N. Monroe Hopkins. Wireless telegraphy is brought up to date, and other recent discoveries are noticed.

The new edition, owing to the great amount of new matter, is published in two volumes. It presents the more recent developments in modern science, and gives information which assists the reader in comprehending the great scientific questions of the day.

GEORGE M. HOPKINS.

New York, June, 1902.

CONTENTS.

Chapter I.—Properties of Bodies.

PAGES

Extension and Impenetrability—Cotton and Alcohol Experiments—Solution of Sugar in Water—Reduction of Volume of Alcohol and Water Mixture—Mixture of Sulphuric Acid and Water—Divisibility—Example of Extreme Divisibility—Porosity—Physical and Sensible Pores—Porosity of Wood—Mercurial Shower—Porosity in Nature — Porosity in the Arts — Compressibility — Pneumatic Syringe—Elasticity—Gases and Liquids Perfectly Elastic—Elasticity of Flexure—Elasticity of Torsion—Experiment showing the Elasticity of Glass.. 1 to 7

Chapter II.—Rest, Motion, and Force.

When a Body is at Rest—All Bodies continually changing Position—Absolute Rest Possible—Inertia—Force—Matter Incapable of changing from Rest to Motion, or the Reverse—Equalizing Effect of Fly Wheels—Persistent Rotation due to Inertia—Action of Projectiles, Hammers, Drop Presses and the Hydraulic Ram, due to Inertia—Inertia Locomotive—Friction due to Roughnesses—The Effect of a Lubricant—Silding Friction—Rolling Friction—Roller and Ball Bearings—Centrifugal Force—Centrifugal Railway—Normal Path of a Moving Body a Straight Line—Spiral Railway—Effect of Centrifugal Force on Air—Choral Top—Effect of Centrifugal Force on Liquids—The Glass Top—Effect of Centrifugal Force on Liquids of Different Densities contained in the Same Vessel—A Scientific Top—Persistence in maintaining Plane of Rotation—Gyroscopic Action—Examples of Centrifugal Action—Oblate Spheroid—Centrifugal Hero's Fountain... .... 8 to 18

Chapter III.—The Gyroscope.

Toy Gyroscope—A Large Gyroscope—Gyroscope with Friction Driving Gear—Pneumatic Gyroscopes—Electrical Gyroscope—Steam Gyroscope—Gyroscopes for showing the Rotation of the Earth—Equatorially Mounted Electrical Indicator—Bursting of Fly Wheels by Gyroscopic Action—Flexible Fly Wheel......... ....19 to 37

Chapter IV.—Falling Bodies—Inclined Plane—The Pendulum.

In a Vacuum All Bodies fall with Equal Rapidity—Effect of Resistance on Falling Bodies—Water Hammer—Swiftest Descent Apparatus

PAGES

—Inclined Plane—Concave Circular Curve—Cycloidal Curve—Isochronal Curve—Method of describing the Cycloid—Dropped and Projected Balls—Gun for dropping and projecting Balls—Oscillating and Conical Pendulums—Variations in Length of Seconds Pendulum at Different Places—Galileo's Discovery—Isochronism of the Pendulum—Length of Pendulum—Foucault's Experiment showing the Rotation of the Earth—Pendulum with Audible Beats—Kater's Reversible Pendulum—Measurement of Time by the Pendulum—Huyghens' Invention—Torsion Pendulum—Hooke's Invention—The Balance—Flying Pendulum.....................38 to 55

CHAPTER V.—MOLECULAR ACTIONS.

Cohesion—A Demonstration of Cohesion—Strain—Prince Rupert's Drops—Bologna Flask—The Breaking of Lamp Chimneys and Water Gauge Tubes—Adhesion—Surface Tension—Surface Tension exhibited in Water Drops—Oil Globule suspended in Equilibrium—Capillarity—Capillary Elevation and Depression—Designs on Wire Cloth—Absorption of Gases—Absorption of Carbonic Acid by Charcoal—Preparation of Carbonic Acid Gas—Diffusion of Gases—Endosmose—Exosmose—Simple Way of showing the Diffusion of Gases—Pressure by Endosmose—Vacuum by Exosmose—The Law governing the Diffusion of Gases—Endosmometer..56 to 71

CHAPTER VI.—LIQUIDS—PRESSURE EXERTED BY LIQUIDS.

Pascal's Law of the Pressures of Liquids—Demonstration of Pascal's Law—Pascal's Experiment—Equilibrium in Communicating Vessels—Principle of the Hydraulic Press—Hypothetical Hydraulic Press—Simple Hydraulic Press—Lateral Pressure—Rectilinear and Rotary Motion produced by Reaction—Hydraulic Ram—Superposition of Liquids of Different Densities—Vial of Four Liquids—Effect of Liquids of Different Densities—Cartesian Diver........72 to 84

CHAPTER VII.—GASES.

Gases are Elastic Fluids—Expansion of Gases—The Air in a State of Equilibrium—Expansibility of Air—Dilatation of Balloon in a Vacuum—Weighing of Gases—Wheel operated by Gas—Determination of the Weight of Air—Hand Glass—Effects of Air Pressure—Crushing Force of the Atmosphere—The Weight lifted by the Air Pressure—The Barometer—Mercurial Column supported by Atmospheric Pressure—Torricelli's Experiment—Pascal's Experiment—Simple Air Pump—Testing the Air Pump—Water boiling in Vacuo—Rarefied Air a Poor Conductor of Sound—Bell in Vacuo—Destruction of Life by Removal of Air—Desiccation by Removal of Air—The Ball Experiment—Card Experiment—Atom-

PAGES
izing Petroleum Burner—Aspirators for Laboratory Use—Bunsen Filter Pump—Elongation of Discharge Pipe of Bunsen Filter Pump necessary to Best Effects—Chapman's Metallic Aspirator—Principle of the Giffard Injector—Experiment with the Aspirator—Exhausting a Geissler Tube—Blast produced by the Aspirator—Plate and Receiver for Aspirator—Mouth Vacuum Apparatus—Hero's Fountain—Wirtz's Pump—Inertia of Air—The Flight of Birds—The Operation of Windmills and Propulsion of Sailing Vessels due to Inertia of Air—Aerial Top—The Fly Wheel—Mechanical Bird—The Boomerang—Vortex Rings........................85 to 115

CHAPTER VIII.—SOUND.

Toys as Experimental Apparatus—Sound a Sensation of the Ear—Sound due to Irregular Vibrations—Musical Sounds due to Rapid and Uniform Vibrations—The Cricket or Rattle—The Buzz as Savart's Wheel—Vibrating Rods—Tranverse Vibration of Rods—The Zylophone—Tuning the Zylophone—The Metallophone—The Musical Box a Reed Instrument—Mouth Organ or Harmonica an Example of a Reed Instrument—Tuning Reed Instruments—The Bugle—Longitudinal Vibrations of Rods—Of a Steel Rod—Longitudinal Vibrations of Wooden Rods—Marloye's Harp—Stopped Pipe—Pandean Pipes—Open Pipes—Flageolet—Ocorina—Stringed Instruments—Lateral Vibrations of Strings—Zither—Division of Strings into Vibrating Segments—Vibrations of Strings by Sympathy—Conduction of Sound—The String Telephone—Harmonic Vibrations—Cumulative Effects of Harmonic Vibrations—Vibration of Railroad Bridges—Slow Vibratory Period of the East River Bridge—The Breaking of an Iron Girder by Bombardment of Pith Balls—Steel Bar vibrated by Drops of Water—By Magnetic Impulses—Sound Recorder—Tracings of the Motion of a Telephone Diaphragm—Vibrating Flames—Simple Device for showing Vibrating Flames—The Speaking Flame—Annular Burner for producing Vibrating Flames—Manometric Flames—Composition of Vibrations—Optical Method of studying Sonorous Vibrations—Apparatus for producing Lissajous' Figures—Re-enforcement of Sound—Resonance studied by Simple Apparatus—Selective Power of a Resonant Vessel—Bell and Resonator—Mouth used as a Resonator—Experiment with the Jew's Harp—Tuning Forks and Resonant Tubes—Musical Flames—Apparatus for the Production of Sounding Flames—Analyzing Vibrating Flames by a Revolving Mirror—A Simple Phonograph—The Perfected Phonograph—Edison's New Phonograph—Edison listening to the First Phonogram from England—The Phonographic Record—Reflection and Concentration of Sound—Adjustable Sound Reflector—Reflection of Light and Sound—Trevelyan Rocker—Refraction of Sound—Sound Lens—The Sensitive Flame—Apparatus for producing Gas Pressure for Sensitive Flame—Sensitive Flame

PAGES

with Gas at the Ordinary Pressure—Determining Speed by Resonance—Siren for measuring Velocities........................116 to 172

CHAPTER IX.—EXPERIMENTS WITH THE SCIENTIFIC TOP.

Siren applied to the Top—Savart's Wheel—Gyrating Perforated Disk—Gyrating Disk with Polished Beads—Chameleon Top—Changes of Hue by the Shifting of the Cover Disk—Phantom Forms—Revolving Mirror—Koenig's Manometric Flames..................... 173 to 180

CHAPTER X.—HEAT.

Heat the Manifestation of Rapid Vibratory Motion of Molecules—A Heated Mass can impart Vibratory Motion to Ether—Heat partially or wholly balances Molecular Attraction—Expansion—A Metallic Thermometer—Simple Thermostat—Air Thermometer—Pulse Glass—Thermoscopic Balance—Electric Meter on the Principle of the Thermoscopic Balance—Wollaston's Cryophorus—Freezing by Rapid Evaporation—The Radiometer—Tyndall's Experiment on Radiant Heat—Action of Radiant Heat on Different Gases—Reflection and Concentration of Heat—Conduction of Heat—Conductivity of Different Metals—Heat due to Friction—Heat due to Pressure and Compression—Pneumatic Syringe—Force of Steam—Candle Bomb—Steam Engine—Fifty Cent Steam Engine—Ascensional Power of Heated Air—Hot Air Motor—Hygrometry—Toy Hygroscope—Sensitive Leaf—Chemical Thermoscope—Hydroscopic and Luminous Roses .. ..181 to 199

CHAPTER XI.—LIGHT.

Theories of Light—The Emission Theory—Undulatory Theory—Comparison of Sound and Light Waves—Sound propagated by Compression and Rarefaction—Vibrations of Light at Right Angles with its Line of Progression—Ether—Reflection—Refraction—Huyghens' Explanation of Refraction—Prisms—Course of Light through a Prism—Polyprism—Lenses—Hypothetical Lens—Forms of Lenses—Converging or Magnifying Lenses—Principal Focus of a Convex Lens—Concave Lens—Converging Rays with a Convex Lens—Diverging Rays with a Concave Lens—Real and Diminished Image—Real and Magnified Image—Virtual Image with Convex Lens—Water Bulb Magnifier—Mirrors—A Convex Cylindrical Mirror—Concave Cylindrical Mirror—Caustics—Convex Spherical Mirror—Concave Spherical Mirror—Phantom Bouquet—Multiple Reflection—The Kaleidoscope—Analysis and Synthesis of Light—Rocking Prism—The Spectrum—Simple Method of producing the Spectrum—Apparatus for producing the Spectrum—Chromatrope—The Blending of Surface Colors—Persistence of Vision—Zoetrope—Irradiation—Examples of Irradiation—Intensity of Light—The Light

PAGES
of the Sun—The Light of the Moon—Measurement of Light—Photometer—Optical Illusions—Illusion from Engineering Drawings—Apparent Deviation by Oblique Lines—Apparent Displacement of a Single Oblique Line—Curious Optical Illusions—Prof. Thompson's Optical Illusions—Webster's Optical Illusions—Rapieff's Optical Illusions.. ....200 to 232

CHAPTER XII.—POLARIZED LIGHT.

Glass, Single Refracting—Double Refracting Bodies—Iceland Spar—The Investigation of Newton on the Properties of Light--Course of Light through Iceland Spar—Nicol's Prism the Most Perfect Instrument for Polarizing—Tourmaline Crystals—Polarization by Reflection and Refraction—Angle of Polarizing for Glass—Stewart's Explanation of Polarized Light by Reflection—Arrangement of Polarizer and Analyzer—Simple Experiment in Polarized Light—Polarizing by Reflection from Blackened Glass—Analyzing by Bundle of Glass Plates—Strained Glass—Glass strained by Pressure—Glass strained by Heat—Polarizing and analyzing with a Single Bundle of Plates—Norremberg Doubler—Double Polarization with a Single Glass Plate—Mica Objects for the Polariscope—Mica Semi-cylinder—Mica Semi-cylinders crossed—Mica Cone—Maltese Cross—Mica Wheel—Star, Fan, and Crossed Bars of Mica—Polariscopes—Simple Norremberg Doubler—Half and Quarter Wave Films—Wide-angled Crystals — Hoffman's Improvement — Polariscope for exhibiting Wide-angled Crystals—Examination of Various Crystals with the Polariscope—Tourmaline Tongs—The Polariscope a Test for Quartz Lenses—Polariscope for Large Objects—Examination of Glassware, etc., by Polariscope—Simple Polariscope for Microscopic Objects—Construction of Simple Polarizer and Analyzer--Method of holding Cover Glasses for cleaning—Practical Applications of the Polariscope—Wheatstone's Polar Clock—Suggestions in Decorative Art—Various Crystals and Combinations of Crystals................233 to 277

CHAPTER XIII.—MICROSCOPY.

Microscopic Objects—Microscopy in Chemistry and Mineralogy—The Microscope a Necessity to the Physicist—Inexpensive Microscope—Water Lens Microscope—Water Lens Microscope with Stand—Compound Microscope—Accessories for the Compound Microscope—Diaphragm and Fine Adjustment—Substitute for the Revolving Table—Illumination of Microscopic Objects—A Modern Microscope—Light Modifier—Iris Diaphragm—Sub-stage Condenser—Gathering Microscopic Objects—Various Books on Microscopy—Implements for gathering Microscopic Objects—Various Microscopic Objects—Transferring Objects to the Slide—Compressor—Microscopic Examination of Ciliated Objects by Intermittent Light—Light Interrupter for the Microscope —Circulation in Animal and Vegetable Tissues—Simple Frog Plate—Circulation of Blood in a

PAGES

Fish's Tail—Quick Method of Mounting Dry Objects—Dr. Stiles' Wax Cell—Microscopic Examination of the Phenomenon of Colors in Thin Plates—Newton's Rings for Microscopic Examination—Microscopic Examination of Soap Films—Of Mica Plates—Of Vibrating Rods—Simple Polariscope for the Microscope—Objects for the Polariscope.... .. ..278 to 308

CHAPTER XIV.—THE TELESCOPE.

Inexpensive Telescope—Terrestrial and Celestial Eyepiece for the Telescope—Collimation—Objects to be examined by the Telescope—Simple Telescope Stand—Compact Telescope..................309 to 317

CHAPTER XV.—PHOTOGRAPHY.

Manipulative Skill in Photography—Dry Plates—The Lens—The Camera Box—The Plate Holder—Focusing Cloth—Exposures—Management of a Camera—Timing the Exposure—Copying—Development of the Plate—Treatment for Overexposure—For Underexposure—Beach's Pyro-Potash Developer—Washing and Clearing or Fixing—The Fixing Solution—Hydrochinon Developer—Lantern Slides—Photographic Printing—Toning—Solution for Black Tones—Solution for Brown Tones—Fixing Bath—Mounting Prints—A Pocket Camera—Simple Photographic and Photo-Micrographic Apparatus—Arrangement of Microscope and Camera for Photo-Micrography—Daguerreotypy—The Invention of Daguerre—Scouring the Plate—Buffing the Plate—Sensitizing—The Dark Room—The Operating Room—Developing the Plate—Fixing—Gilding or Toning—Mounting...................... . ...318 to 346

CHAPTER XVI.—MAGNETISM.

Magnetism by Induction from the Earth—By Torsion—Magnetization of Straight and U-shaped Bars—Motion produced by a Permanent Magnet—Effect of the Armature—Effect of Permanent Magnet on a Bar magnetized by Induction—Neutralizing Effect of an Opposing Pole—Neutral Point between Unlike Poles—Consequent Pole—Formation of Magnetic Curves—Magnetic Curves in Relief—Arborescent Magnetic Figures—Floating Magnets—Mayer's Floating Needles—Rolling Armature—Magnetic Top...... ....347 to 358

CHAPTER XVII.—FRICTIONAL ELECTRICITY.

Action of Frictional Electricity on Pith Balls—Electric Pendulum—Electroscope—Masked Electricity—Ano-Kato—Mutual Repulsion of Electrified Threads—Self-luminous Buoy—Electrical Machines—Electrophorus—Winter's Electrical Machine—Modified Wimshurst Electrical Machine—Attachment of Leyden Jar—Distribution of Electricity on the Wimshurst Plates—Experiments with the Induction Machine—Various Phases of the Electrical Discharge—Length-

PAGES

ening the Spark—Diversion of the Discharge by Moisture—Glow at the Positive Collector—Glow at the Negative Collector—Discharge through a Geissler Tube—Franklin's Plate—Leyden Jar—Measuring Jar—Disruptive Effect of the Discharge—Electrical Chime—Electric Fly—Fly on Inclined Plane—Jointed and Universal Dischargers—Insulating Stool—Insulated Sphere—Cylindrical Conductor--Gas Pistol—Electric Mortar—Dancing Pith Balls—Gassiot's Cascade—Pith Ball Electroscope........................359 to 391

CHAPTER XVIII.—DYNAMIC ELECTRICITY.

Generator of the Electric Current—Experimental Battery and Galvanometer—Polarization—Single-Fluid Batteries—Smee's Battery—Grenet Battery—Simple Plunge Battery—Large Plunge Battery—Forming the Lining for Battery Cells—Chloride of Silver Cell—Leclanche Battery—Dr. Gassner's Dry Battery—Caustic Potash Battery—Two-Fluid Batteries—Daniell Battery—Gravity—Grove—Chromic Acid—The Fuller Cell—Mechanical Depolarization of Electrodes—Application of Air Jets to Depolarization—Mechanical Agitator for Depolarizing—Secondary Battery—Roughening the Plate—Method of Connecting the Plates—Forming the Cell—Thermo-Electric Battery—Electrical Units—Arrangement of Battery Cells—Galvanometers—Deprez-D'Arsonval Galvanometer—Arrangement of Galvanometer, Lamp, and Scale—Tangent Galvanometer—Circuit of the Tangent Galvanometer—Electrical Measurements—Wheatstone's Bridge—Resistance Box Connections—Bridge Key—Branch Circuits—Joint Resistance of Branch Circuits—Expansion Voltmeter—Ammeter—Recording Voltmeter—Electro-Magnets—Magnet for Experimentation—Magnet and Switch—Inexpensive Magnet—Form for the Coils—Foucault's Experiment—Experiments with the Electro-Magnet—Diamagnetism—Experiments illustrating the Principle of the Dynamo—Magnetization of a Steel Bar—Magneto-electric Induction—Magnetic Induction—Induced Currents from Induced Magnetism—Simple Current Generator—Simple Motor—Fifty Cent Electric Motor—Gramme Machine for Illustration—Armature and Magnetic Fluid—Drum Armature—Magneto Electric Machines—Principle of the Bell Telephone—Magnetic Key—Polarized Bells—Annunciator—Hand Power Dynamo—Details of Construction of Hand Power Dynamo—Electro-plating Dynamo—Connections of Plating Dynamo—Simple Electric Motor—Details of Construction of Simple Electric Motor—Circuit of the Simple Electric Motor—Cast Iron Magnet..392 to 509

CHAPTER XIX.—QUARTER-HORSE POWER ELECTRIC MOTOR.

Quarter-Horse Power Electric Motor—Field Magnet—Armature Core—The Winding—The Commutator—The Journal Box—Starting Box—Motor as a Dynamo—Table of Tangents....................510 to 523

EXPERIMENTAL SCIENCE

CHAPTER I.

PROPERTIES OF BODIES.

Extension, impenetrability, divisibility, porosity, compressibility, elasticity, inertia, and gravity are general properties common to all bodies, whether solid, liquid, or gaseous, while some bodies possess specific properties, such as solidity, fluidity, tenacity, malleability, color, hardness.

EXTENSION AND IMPENETRABILITY.

To all matter must be attributed two essential qualities: first, that in virtue of which it occupies space, and which is

FIG. 1.

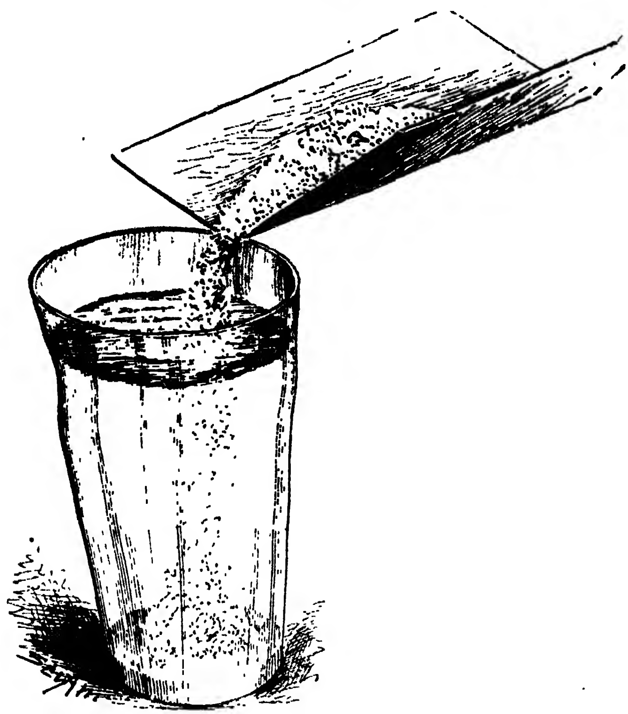
A Hatful of Cotton in a Tumblerful of Alcohol.

known as extension, and, second, that which allows only one particle or atom of matter to occupy a given space—the

property known as impenetrability. That matter occupies space is appreciated by our senses, and needs no particular proof, but that two portions of matter cannot occupy the same space at the same time sometimes seems anomalous, as is shown by some of the following experiments.

Into a tumbler filled with alcohol may be crowded a hat-ful of loose cotton without causing the alcohol to overflow.* The success of the experiment depends upon the slow intro-

FIG. 2.



Solution of Sugar in Water.

duction of the cotton, allowing the alcohol to invest the fibers, before they are fairly plunged beneath the surface of the alcohol.

In this experiment the penetration of the alcohol is only apparent; the fibers displace some of the alcohol, but the quantity is so small as not to be observable. If the cotton were compressed to the smallest possible volume, it would be found to occupy but very little space. So small a body

* See also chapter on projection.

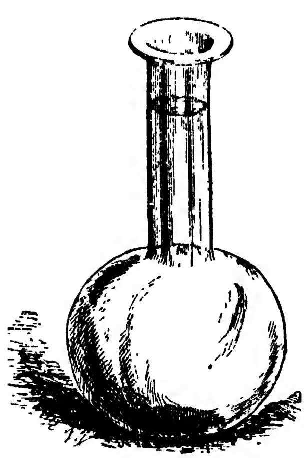
would be incapable of raising the level of the alcohol enough to be appreciable by an ordinary observer.

A more puzzling experiment consists in slowly introducing some fine sugar into a tumblerful of warm water. A considerable quantity of sugar may be dissolved in the water without increasing its bulk appreciably.

Here the physicist is forced to acknowledge that either the water is penetrated or its atoms are so disposed as to receive the sugar between them, possibly in the same way as a scuttle filled with coal might contain also a bucketful of sand. This latter view is adhered to. The atom or ultimate particle is held to be impenetrable.

In the case of the mixture of water and alcohol, or water

FIG. 3.



Representing Volume of Unmixed Alcohol and Water.

FIG. 4.

Reduction of Volume of Alcohol and Water Mixture.

and sulphuric acid, a curious phenomenon is presented. Take alcohol and water for example. Equal volumes of alcohol and water, when mixed, occupy less space than when separate. If the sum of the volumes of the two separate liquids is 100, the volume of the mixture will be only 94. In the case of the mixture of sulphuric acid and water, the difference is greater.

An easy way to perform this experiment is to fill a narrow-necked flask up to a line which may conveniently be marked by a rubber band around the neck, then removing one-half

of the water, measuring it exactly, and replacing it with a volume of alcohol exactly equal to that of the water removed. It will be found that when the liquids are mixed, the mixture will not fill the flask up to the original mark.*

The only reasonable explanation of this phenomenon is that the molecules of the two liquids accommodate themselves to each other in such a manner as to reduce the pores, and thus diminish the volume of the mixture.

DIVISIBILITY.

The property of a body which admits of separating it into distinct parts, and which is known as divisibility, is possessed by all matter. An example of extreme divisibility is found in the coloring of a pail of water with a minute particle of aniline.

POROSITY.

There are two kinds of pores, viz., physical or intermolecular pores and sensible pores. In the case of the former, the interspaces are so small that the molecules are within each other's influence and may attract or repel each other. Expansion by heat, contraction by reduction of temperature, and reduction of volume by compression are among examples of phenomena rendered possible by the existence of physical pores.

Sensible pores are small cavities or spaces, across which molecular forces are unable to act.

The experiment illustrated by Fig. 5 shows the existence of sensible pores. In the neck of an Argand chimney is inserted a plug of Malacca wood, which is sealed around the periphery with wax or paraffine. In the top of the chimney is inserted a stopper, through which projects a short glass tube, having its upper end bent over or capped with a small test tube. To the outer end of the glass tube is applied a rubber tube. When the chimney is in an inverted position, as shown in the engraving, a quantity of mercury is placed in the larger part of the chimney, and the air is partly exhausted from the chimney, by applying the mouth to the

* See also chapter on projection.

rubber tube and sucking. The mercury readily passes through the porous wood and falls in a shower. By employing an air pump for producing the partial vacuum, the mercury may be drawn through a plug of pine. These experiments show in a striking manner the porosity in a longitudinal direction of these pieces of wood.

Wood, vegetable, and animal tissues, sponge, pumice stone, and many other substances have sensible pores that

FIG. 5.

Mercurial Shower.

may readily be seen. Physical pores cannot be seen even by the aid of the most powerful microscope; but their existence is proved by the fact that all bodies may be compressed or diminished in volume.

Sensible pores play an important part in the operations of nature, especially in the vegetable and animal kingdoms.

The property of porosity is utilized in the arts, in the

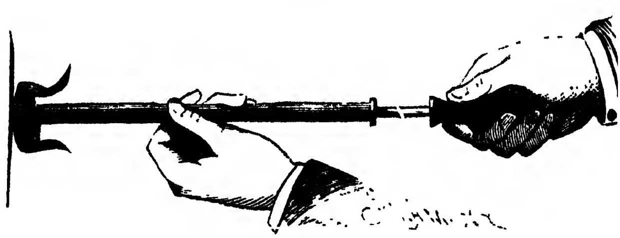
filtration of liquids, in the absorption of liquids and gases, in electrolytic processes, in assaying, etc.

COMPRESSIBILITY.

The property by virtue of which a body may be diminished in volume, by pressure, without losing weight, is known as compressibility. This property is possessed in the greatest degree by gases, which may be reduced by compression to from one-tenth to one-hundredth their original volume.

The simplest piece of apparatus for showing the compression of a gas is a well-made toy popgun, such for example as that shown in Fig. 6. By closing the mouth of this gun by means of a piece of sheet metal or mica, and oiling

FIG. 6



The Popgun used as a Pneumatic Syringe.

the piston well with a heavy oil, to prevent the escape of air from the barrel, it may readily be shown that the air contained by the barrel may be greatly reduced in volume by simply pushing in the piston.

ELASTICITY.*

When a body resumes its original form or volume after distortion or compression, it possesses the property of elasticity, and is therefore known as an elastic body. Elasticity may be shown by pressure, by bending, by torsion or twisting, or by tension or stretching. Gases and liquids are perfectly elastic. When compressed and afterward allowed to

* See also chapter on projection.

return to their original pressure, they are found to possess exactly their original volume.

Among solids, glass is apparently perfectly elastic. A plate of glass bent under pressure and allowed to remain under stress for twenty-five years, when released and carefully tested for any permanent set, was found to have returned to exactly its original shape. Elasticity by flexure or bending is seen in various springs, such as carriage springs, gun-lock springs, etc.

The elasticity of torsion is exhibited by door springs of certain forms, spiral springs, and by twisted threads of cotton, linen, and other material. The elasticity of tension is shown in the strings of all stringed musical instruments, and notably in soft rubber in its various forms.

CHAPTER II.

REST, MOTION, AND FORCE.

A body is said to be at rest when its position is not being changed, but this statement needs some qualification, since any rest known to us is only relative. All bodies with which we are acquainted are continually changing their position either in relation to adjacent objects or along with adjacent objects relatively to distant objects. For example: a bowlder is said to be at rest when it maintains its position relative to the earth's surface, but since the earth itself is not at rest, it is evident that whatever is fixed on the face of the earth cannot be at rest.

On the other hand, if the bowlder were rolling down a declivity, it would be changing its position relative to the earth's surface as well as to all other objects, and would therefore be said to be in motion; but a body may be apparently in motion while in reality absolutely at rest. If we were to suppose a body projected from the earth into space with a velocity equal to that of the earth, but in a direction opposite that of tne earth's motion and uninfluenced by heavenly bodies, the body, although having apparently a high velocity relative to the earth, would be absolutely at rest.

INERTIA.

No body is of itself able to change from a state of rest to a state of motion, neither can a body in motion change its direction or pass unaided to a state of rest. That which causes or tends to cause a body to pass from a state of rest to one of motion, or accelerates or retards the motion of a body, or changes its direction, is known as Force. The incapability of matter to change from rest to motion, or the reverse, is a negative property known as Inertia.

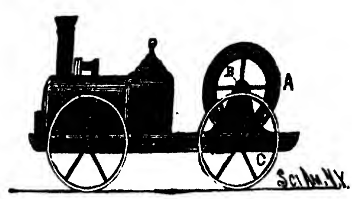
To inertia is due the equalizing effect of flywheels; when

set in motion, they tend to maintain their revolution in opposition to considerable resistance. If sufficient force is applied to the flywheel to counteract the resistance, a practically equable motion is secured, even though the force applied be an intermittent one.

The top is an example of persistent rotation due to inertia. To inertia is due the action of projectiles, hammers, drop-presses, also the hydraulic ram.

The property of inertia, the storage of power, the transfer of power by friction, and the conversion of rotary into rectilinear motion are illustrated by the toy locomotive shown in the annexed engraving. The flywheel, A, is mounted on the shaft, B, which rests on the supporting and driving wheels, C. The wheel, A, is spun by means of a string in the same manner as a top. By virtue of its inertia, the wheel, A, tends to continue its rotary motion. If unaffected by outside influences, it would run on forever; but the friction of its bearings and of the air and other causes combine to bring it to rest.

FIG. 7



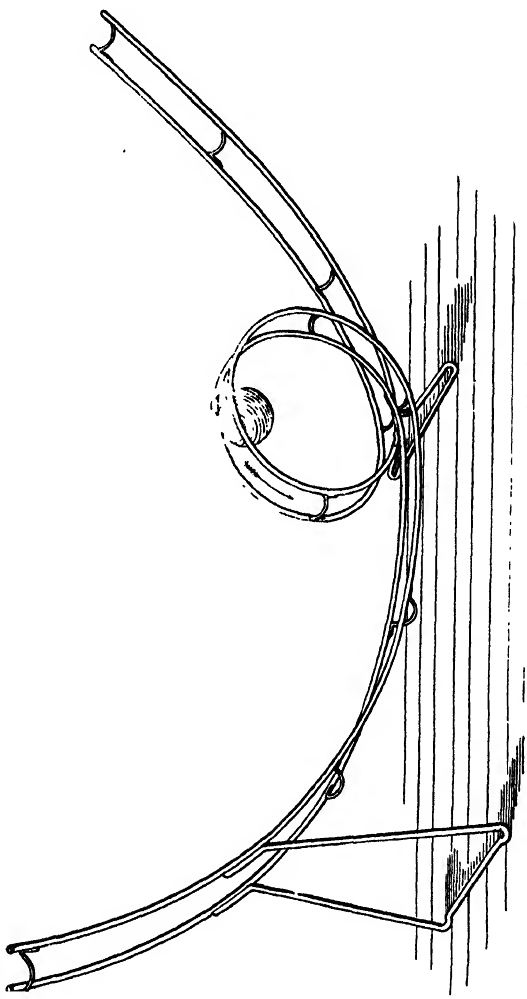
Inertia Locomotive.

The power imparted to and stored in the wheel, A, is given out in turning the wheels, C, overcoming friction, and propelling the machine forward.

FRICTION.

The resistance caused by the moving of one body in contact with another is known as friction. No perfectly smooth surface can be produced, all surfaces having minute projections or roughnesses, so that when the surfaces of any two bodies are moved in contact with each other, the projections of one body engage the projections of the other body, thus offering resistance to the free motion of the bodies. When the surfaces are covered witn a lubricant, their inequalities are filled and smoothed over and the friction is lessened.

The friction developed by the sliding of one body upon another is known as "sliding friction," and the kind developed by the rolling of a body upon another is "rolling friction." Rolling friction absorbs much less power than sliding friction. Owing to this fact, the journals and steps



FIG

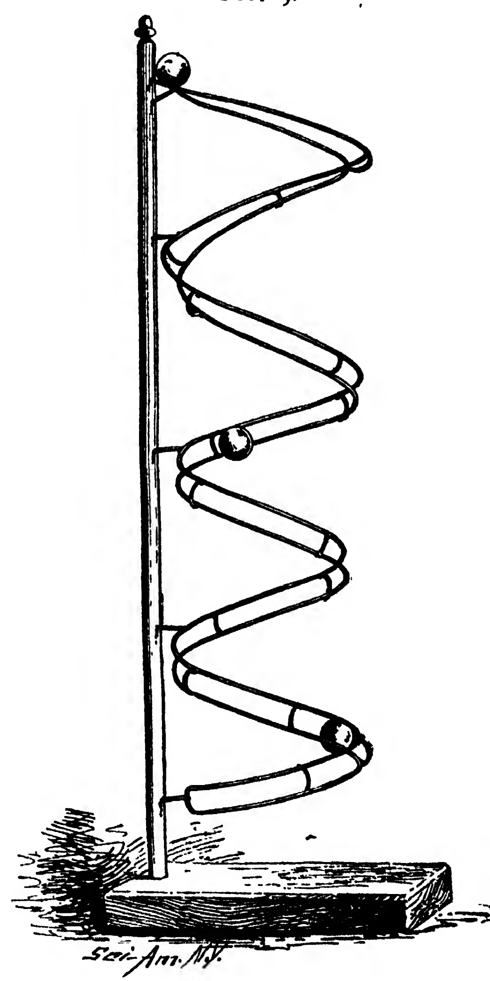
Centrifugal Railway.

of many kinds of machinery are provided with roller or ball bearings, thus substituting rolling for rubbing surfaces. An example of bearings of this kind is found in the pedals and shafts of bicycles and tricycles, which are provided with ball bearings.

CENTRIFUGAL FORCE.

The normal path of any moving body is a straight line; the body can be made to move in a curved path only by restraining it sufficiently to counteract its tendency to leave a circular path and move in a straight line. This tendency is called centrifugal force. When a body moving in a circular path is released, it does not fly off radially, but on a line tangent to the circular path. The fact that a body traveling in a circular path, when released from all restraint, will move in a straight line, proves that the normal path of a moving body is a straight line. The centrifugal railway represented in Fig. 8 shows with what force a restrained body tends to fly from a circular path.

FIG. 9.



Spiral Railway.

This railway is made in the same manner as the swiftest descent apparatus described on another page. Two wires are bent into spiral loops around a cylinder, and the extremities are curved upwardly as shown. The two curved wires are connected together by curved wire cross pieces fastened by soldering, and two wire feet are attached to complete the apparatus. No particular rule is required for the construction of the centrifugal railway. The only precaution necessary is to see that the

height of the higher end of the railway is to the height of the circular part in a greater ratio than 5 to 4.

A ball started at the higher end of the railway follows the track to the opposite end, and at one point in its travel it is held by centrifugal force against the under side of the track in opposition to the force of gravity.

In Fig. 9 another example of centrifugal action is exhibited by a spiral railway upon which a ball rolls down upon a track consisting of two rails arranged vertically one over the other. The track is formed of two wires bent spirally and connected by curved cross pieces, as in the case of the centrifugal railway already described. The upper convolution of the spiral is twisted so that the ball may start on a horizontal track. During its descent on the twisted portion of the track, the ball acquires sufficient momentum to cause it to follow the vertical track, being held outwardly against the rails by centrifugal force. The descent of the ball is accelerated. The spiral railway represented in the engraving is two feet high, six inches in diameter, the rails being $\frac{3}{4}$ inch apart.

FIG. 10.

The Choral Top.

The effect of centrifugal force on air is beautifully exhibited by the ordinary choral top. As the top spins, air, which enters the holes at the top, is discharged through the holes at the equator by centrifugal force. The air, in going through the top, passes through a series of reeds, setting them in vibration, producing agreeable musical sounds.

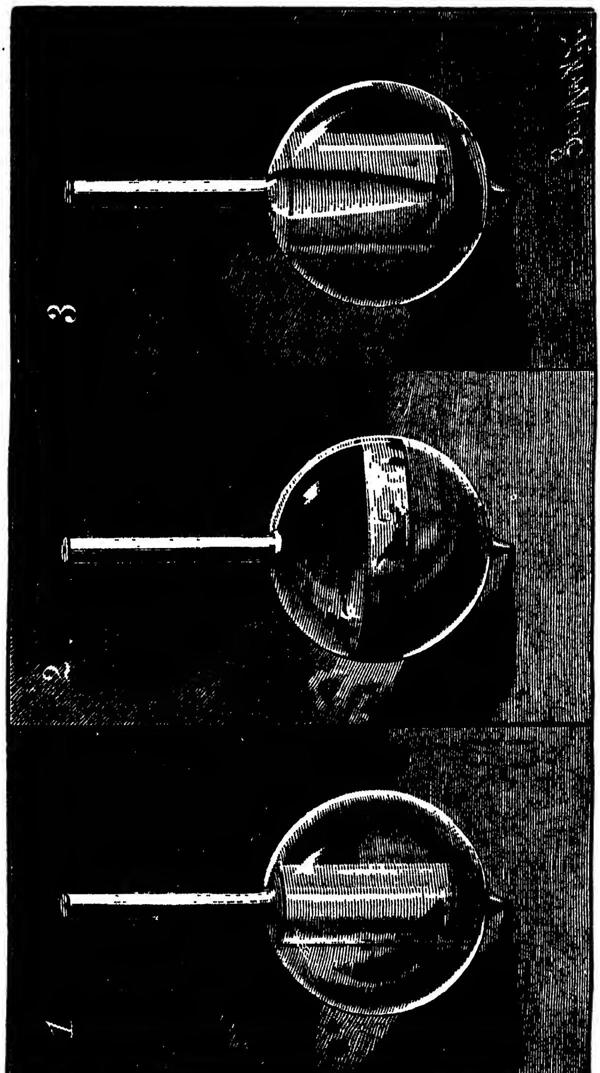
The annexed engraving shows a very simple but effective device for exhibiting the effect of centrifugal force on liquids. It is a hollow glass top of spherical form, having a tubular stem, and a point on which to spin.

These tops are filled with various liquids, some of them containing two or more. The one shown at Fig. 11 is filled partly with water and partly with air. When the top is spun, the water flies as far from the center as possible, leav-

ing in the center of the sphere an air space, which at first is almost perfectly cylindrical, but which gradually assumes the form of a parabola as the velocity of the top diminishes.

At 2 is shown a top having a filling consisting of air,

Fig. 11.



Top for Showing the Action of Centrifugal Force on Liquids.

water, and a small quantity of mercury. The water acts as above described, and the mercury forms a bright band at the equator of the sphere.

At 3 is shown a top containing water and oil (kerosene).

The water, being the heavier liquid, takes the outside position, the oil forming a hollow cylinder with a core of air.

The top, after being filled, is corked and sealed. It is spun by the hands alone or with a string and the ordinary handle. The diameter of the top is 1½ inches. It is made of considerable thickness, to give it the required weight and strength.

A SCIENTIFIC TOP.

Every street urchin can spin a top, and get an unending amount of amusement out of it; but it would seriously puzzle the majority of "boys of larger growth" to satisfactorily explain all the phenomena of this simplest of toys.

Why does it continue to revolve after being set in motion? Why does its motion ever cease? Why does it so persistently maintain its plane of rotation? When its axis is inclined to the vertical, why does it revolve slowly around a new axis while turning rapidly upon its own axis? And when so inclined, why does it gradually right itself until it rotates in a horizontal plane? Why does it not revolve proportionately longer when its speed is increased? These and many other questions arise when we begin the examination of the action of the top. They have all been answered so far as it is possible to answer them, still it is difficult to reach far beyond the mere knowledge of the actions themselves.

The top has already risen to some importance as a scientific toy, but it is worthy of being elevated to the dignity of a truly scientific instrument. To give it that eminence, three things are necessary: first, a considerable weight, and in consequence of this an easy and effective method of spinning, and finally it requires a good bearing, having a minimum of friction.

The top illustrated has these three requisities. It weighs 3½ pounds, and its weight might be increased somewhat with advantage. It has a frictional spinning device by which a velocity of 3,000 revolutions per minute may readily be attained. It is provided with a hardened steel pivot which

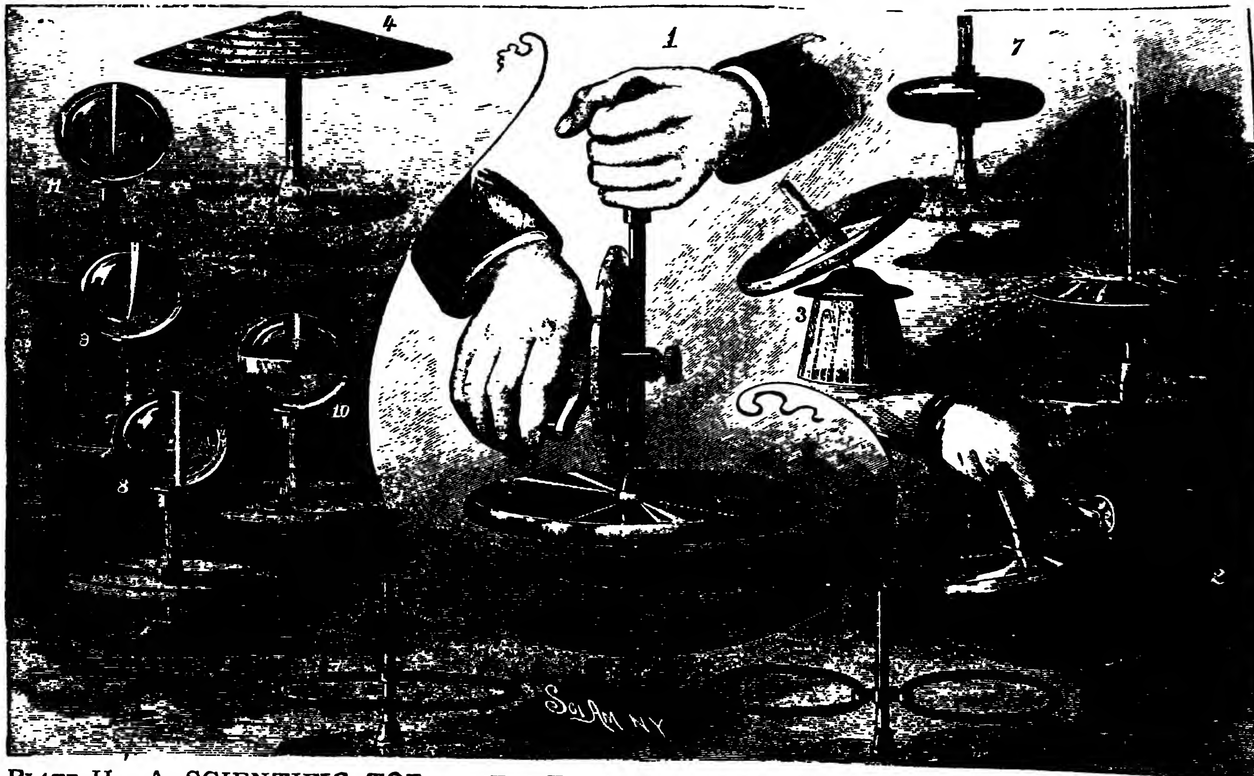


PLATE II.—A SCIENTIFIC TOP.—1. The Top. 2. Persistence in Maintaining Plane of Rotation. 3. Gyroscopic Action. 4, 5, 6. Examples of Centrifugal Action. 7. Formation of Oblate Spheroid. 8, 9, 10, 11. Examples of Centrifugal Action on Liquids. 12. Centrifugal Hero's Fountain.

turns on an agate or steel step.* It is almost perfectly balanced, and the friction of its bearing is very slight. When unencumbered, it will run for over 42 minutes in the open air with once spinning, and its motion may at any time be accelerated without stopping, by a new application of the friction wheel.

The brass body of the top is 6 inches in diameter, and $\frac{5}{8}$ inch thick in the rim. Its steel spindle is $\frac{3}{8}$ inch in diameter and has a tapering longitudinal hole which is $\frac{1}{4}$ inch in diameter at its larger end. To this tapering hole is fitted the tapered end of a rod supporting the stud on which the friction driving wheel turns. The upper end of the rod is provided with a handle, and to the boss of the friction wheel is secured a crank.

A sleeve fixed to the spindle of the top is furnished with an elastic rubber covering which is engaged by the beveled surface of the driving wheel. After imparting the desired speed to the top, by turning the driving wheel, the wheel and the rod by which it is supported may be withdrawn from the top, without interfering in any way with its action.

A large number of interesting experiments may be per formed by means of a top of this character. Most demonstrations possible with the whirling table may be adapted to this top, and, besides, many phenomena peculiar to the top itself may be exhibited. A few of the more striking experiments are illustrated.

By suddenly pressing upon one side of the top with a small rubber-covered wheel, as shown in Fig. 2 (Plate II.), it will be found impossible to change its plane of rotation by the application of any ordinary amount of force. In fact, the side of the top to which the pressure is applied will rise rather than yield to the pressure.

By placing the step of the top on an elevated support, such as a tumbler, as shown in Fig. 3 (Plate II.), and gently pressing against one side of the spindle, the axis of the top will be gradually inclined, and a gyroscopic action will be

* An agate mortar of the smallest size, about $1\frac{1}{4}$ inches in diameter, mounted in a wooden base, forms a very good step; but a steel disk, having a concave upper surface, and made as hard as possible, is preferable.

set up. The top will swing around with a very slow, majestic movement, traveling six or eight turns per minute around a vertical axis while revolving rapidly on its own axis, and it will slowly regain its original position.

As the peripheral speed of the top is almost a mile a minute, a little caution is necessary in handling it while in rapid motion, as any treatment that will cause it to leave its bearings will be sure to result in havoc among the surroundings, besides being liable to injure the operator.

Several methods of showing centrifugal action are illustrated, the simplest being that shown in Fig. 4 (Plate II.) A small Japanese umbrella, about 20 inches in diameter, is arranged to be rotated by the top, by applying to its staff a tube which fits over the spindle of the top. In this, as well as the other experiments, the top is set in motion before the object to be revolved is applied. The tube attached to the umbrella having been placed on the revolving spindle, the arms are thrown up by centrifugal action, thus spreading the umbrella.

Fig. 5 (Plate II.) shows a ring formed of two pieces of heavy rubber tubing secured to two metallic sleeves fitted to a rod adapted to the tapering hole of the top spindle. The lower sleeve is fixed, and the upper one is free to slide up or down on the rod. Normally, the rubber forms a ring, as shown in dotted lines, but, when rotated, the centrifugal force reduces it to a flat ellipse. A similar experiment, in which two elastic rings are secured on opposite sides of the rod, is shown in Fig. 6 (Plate. II.); the rings being circular when stationary and elliptical when revolved.

In Fig. 7 is shown a device for illustrating the formation of an oblate spheroid. A tube, closed at the lower end and fitted to the hole in the top spindle, is provided near its lower end with a fixed collar and a screw collar, between which the lower wall of a hollow flexible rubber sphere is clamped. The upper wall of the sphere is clamped in a similar way between collars on a sleeve arranged to slide on the tube. The tube is perforated above the lower pair of collars to admit of filling the hollow ball with water. When the ball is filled or partly filled with water, and rotated, it

becomes flattened at the poles and increases in diameter at the equator, perfectly illustrating the manner in which the earth received its present form.

The glass water globe represented in motion in Fig. 8 exhibits a cylindrical air space extending through it parallel with the axis of rotation, the water having been carried as far as possible from the center of rotation by centrifugal action.

When the speed of the globe is reduced, gravity asserts itself and the air space assumes a parabolic form, as shown in Fig. 9 (Plate II.)

In the globe represented in Fig. 10 the filling consists of water and mercury. The rotation of the globe causes the mercury to arrange itself in the form of a narrow band at the equator of the globe.

Fig. 11 shows a globe filled with air, oil, and water, which, when the globe is revolved, arrange themselves in the order named, beginning at the center of the globe.*

A Hero's fountain, operated by centrifugal force instead of gravity, is shown in Fig. 12 (Plate II.) The metallic vessel contains three concentric compartments. The jet tube extends downward into the central compartment and is bent laterally, so that it nearly touches the wall of the compartment. The intermediate compartment communicates with the outer compartment, and the outer and central compartments are connected by an air duct. The central and intermediate compartments are filled with water, and as the vessel is revolved the water in the intermediate compartment is carried by centrifugal action into the outer compartment, and, compressing the air contained in that compartment, drives it through the air duct, with a force due to the centrifugal action, into the central compartment, where it exerts a pressure on the water sufficient to cause it to be discharged through the jet.

* See also chapter on projection.

CHAPTER III.

THE GYROSCOPE.

This instrument has always been a puzzle to physicists. Its phenomena seems to be incapable of explanation in a popular way. In view of the complicated nature of the calculations involved, no attempt will here be made to explain the action of the gyroscope mathematically,* the object of the present article being merely to describe a few modifications of the instrument and to mention peculiarities noticed in the performance of some of these modified forms.

FIG. 12.

Toy Gyroscope.

The difficulty of securing a high speed in a large gyroscope led to the application of a friction driving device, as shown in Figs. 13 and 13*a*, by means of which an initial velocity of from 4,500 to 5,000 revolutions per minute may readily be attained.

The instrument, after being set in motion, behaves like other gyroscopes not provided with means for maintaining the rotary motion of the wheel, but its size and the facility with which it may be operated render it very satisfactory.

The gyroscope wheel is 6 inches in diameter, ⅜ inch thick, and, together with its shaft, weighs 3½ pounds. The annular frame weighs 1¾ pounds. So that 5¼ pounds must be sustained by gyroscopic action when the counterbalance is not applied.

The driving wheel is 7¾ inches in diameter. Its face is

* For a mathematical explanation see "Rotary Motion as applied to the Gyroscope." by Gen. J. G. Barnard.

$\frac{3}{4}$ inch wide. Its shaft is journaled in an arm pivoted to the base, with its free end adapted to enter a recess in the edge of the annular frame, for supporting the gyroscopic wheel while motion is being imparted to it. Upon the shaft of the

Fig. 13.

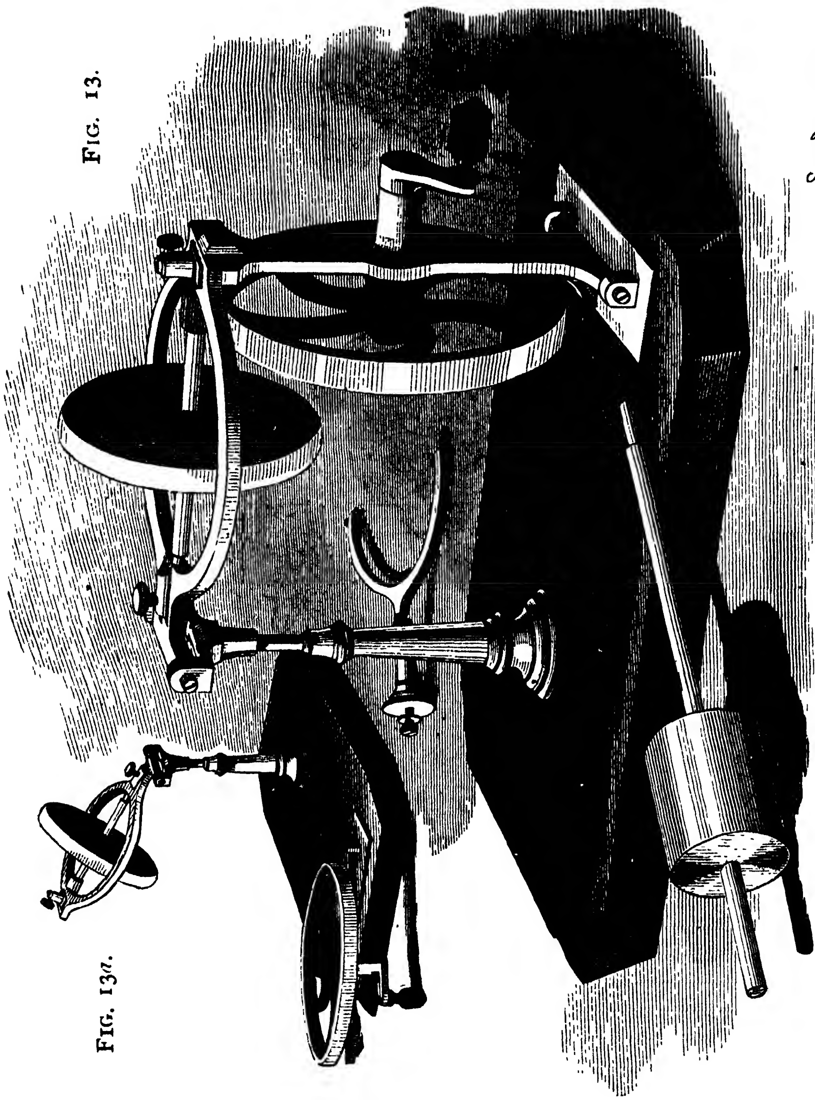


Fig. 13a.

Gyroscope with Friction Driving Gear.

gyroscope wheel is secured a soft rubber tube having an external diameter of nine-sixteenths inch. This shaft makes 13·84 revolutions to one turn of the drive wheel, so that when the drive wheel is turned six times per second, the

gyroscope wheel will make very nearly 5,000 turns per minute (4,982).

This gyroscope may be arranged as a Bohnenberger apparatus by removing the tall standard and attaching the shorter one to the center of the base by means of a bolt. The annular frame of the instrument is suspended on pivotal screws in the extremities of the semicircular support, which is capable of turning on the upper end of the short standard. In the engraving the short standard, together with the semicircular support, is shown lying on the table. The usual counterbalance is also shown lying on the table. Fig. 13 shows the drive wheel in position for imparting motion to the gyroscopic wheel, and Fig. 13*a* shows the driving wheel withdrawn and the gyroscope in action.

As this instrument does not differ from the ordinary one, except in the application of the driving mechanism, it will be unnecessary to go into particulars regarding its performance.

In Figs. 14, 15, and 16 are shown pneumatic gyroscopes, and Fig. 17 represents a steam gyroscope.

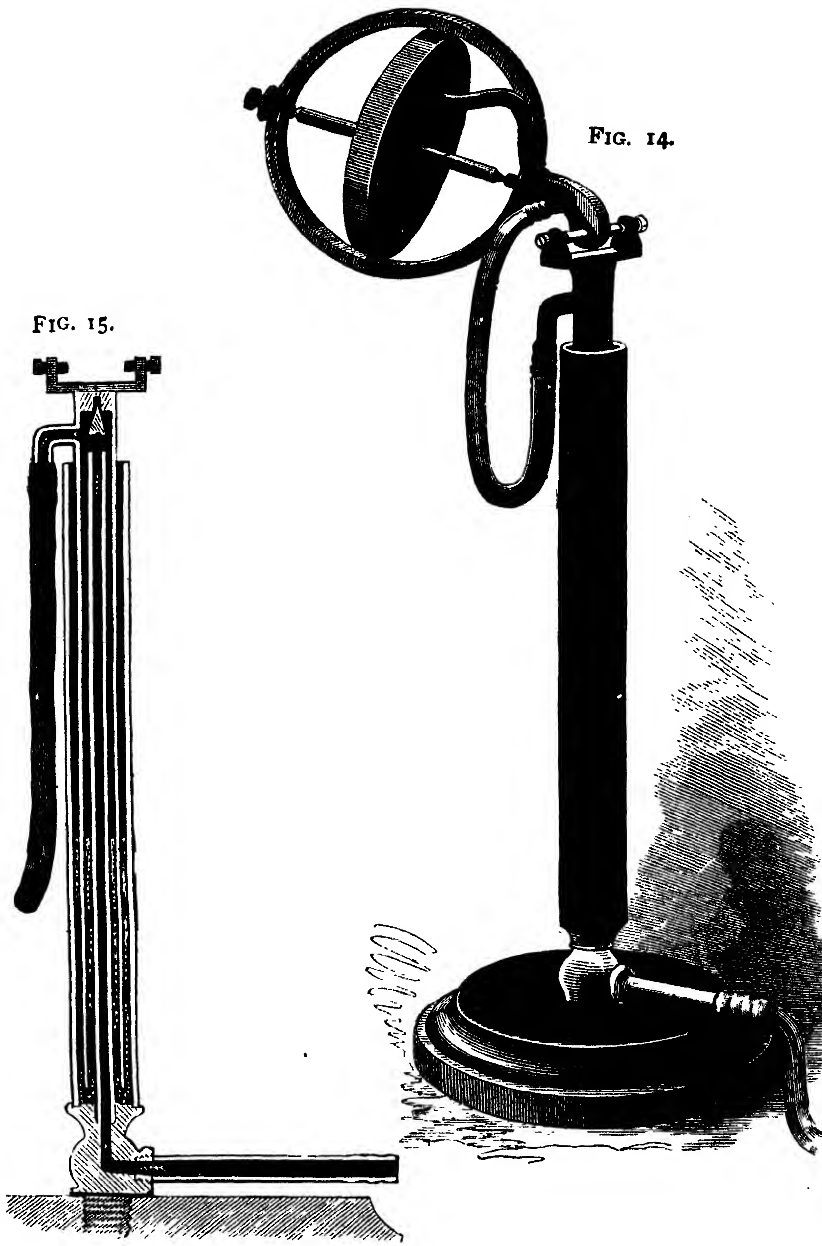
The pneumatic gyroscope shown in Fig. 14 consists of a heavy wheel provided with flat arms arranged diagonally, like the vanes of a windmill. The wheel is pivoted on delicate points in an annular frame having an arm pivoted in a fork at the top of the vertical support. The arm of the annular frame carries a tube, which terminates near the vanes of the wheel in an air nozzle which is directed toward the vanes at the proper angle for securing the highest velocity. The opposite end of the tube is prolonged beyond the pivot of the frame.

The support of the annular frame, shown in vertical section in Fig. 15, consists of an inner and outer tube, the inner tube having a closed upper end terminating in a pivotal point. The lower end of this tube communicates with the horizontal tube, through which air is supplied to the machine.

A sleeve, closed at its upper end and carrying the fork in which the arm of the annular frame is pivoted, is inserted in the space between the inner and outer tubes, and turns

FIG. 14.

FIG. 15.



Pneumatic Gyroscope.

on the pointed end of the inner tube. The inner tube is perforated near its pointed end, to permit of the escape of air to the interior of the sleeve, and the lower end of the sleeve is sealed by a quantity of mercury contained by the space between the inner and outer tubes. The air pipe carried by the annular frame communicates with the upper end of the sleeve by a flexible tube. When air under pressure passes through the inner pointed tube, through the sleeve, and through the air nozzle, and is projected against the vanes of the wheel, the wheel rotates with great rapidity, and the gyroscope behaves in all respects like the electrical gyroscope referred to.

The gyroscope shown in Fig. 16 is adapted to the standard just described, but the heavy wheel is replaced by a very light paper ball, whose rotation is maintained by two tangential air jets, which play upon it on diametrically opposite sides, and nearly oppose each other, so far as their action on the surrounding air is concerned. The rotary motion is produced solely by the friction of the air on the surface of the ball. The upwardly turned nozzle is arranged to deliver an air blast which is a little stronger than that of the lower nozzle, so that a slight reactionary force is secured, which assists the gyroscope in its movement around the vertical pivot sufficiently to cause the ball to maintain its horizontal plane of rotation continuously. In fact, this gyroscope will start from the position of rest, raise itself in a spiral course into a horizontal plane, and afterward continue to rotate in the same plane so long as air under pressure is supplied.

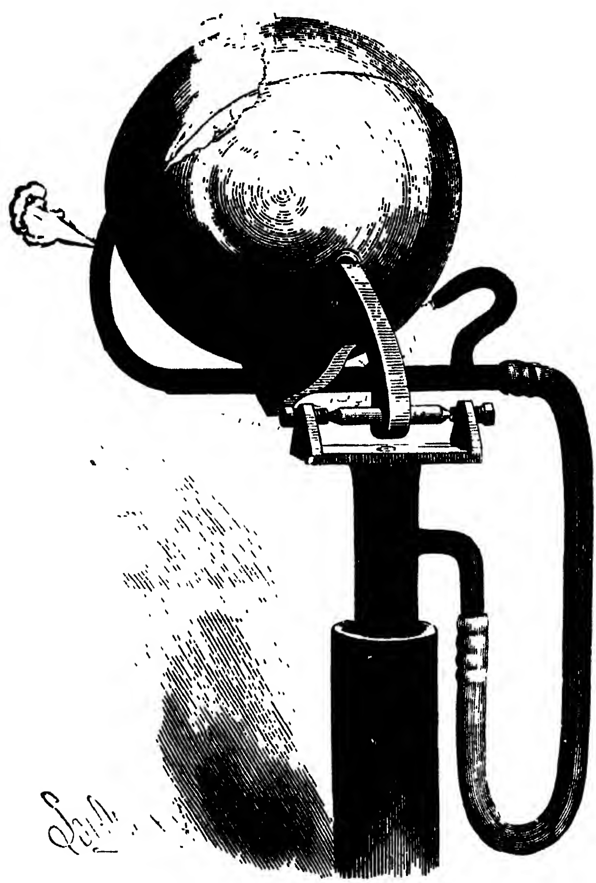
It may be questioned whether this machine is a true gyroscope. However this may be, it is certain that the reactionary power of the stronger air jet is of itself insufficient to produce the motion about the vertical pivot; neither is there a sufficient vacuum at the top of the ball to produce any appreciable lifting effect.

The steam gyroscope shown in Fig. 17 hardly needs explanation. It differs from all the others in generating its own power within its moving parts. The boiler is supported by trunnions resting in a fork arranged to turn on a fine

vertical pivot. The engine is attached to the boiler, so that both engine and boiler swing on the trunnions in a vertical plane. The wheel of the engine is made disproportionately large and heavy, to secure the best gyroscopic action.

The performance of the steam gyroscope is like that of

FIG. 16.



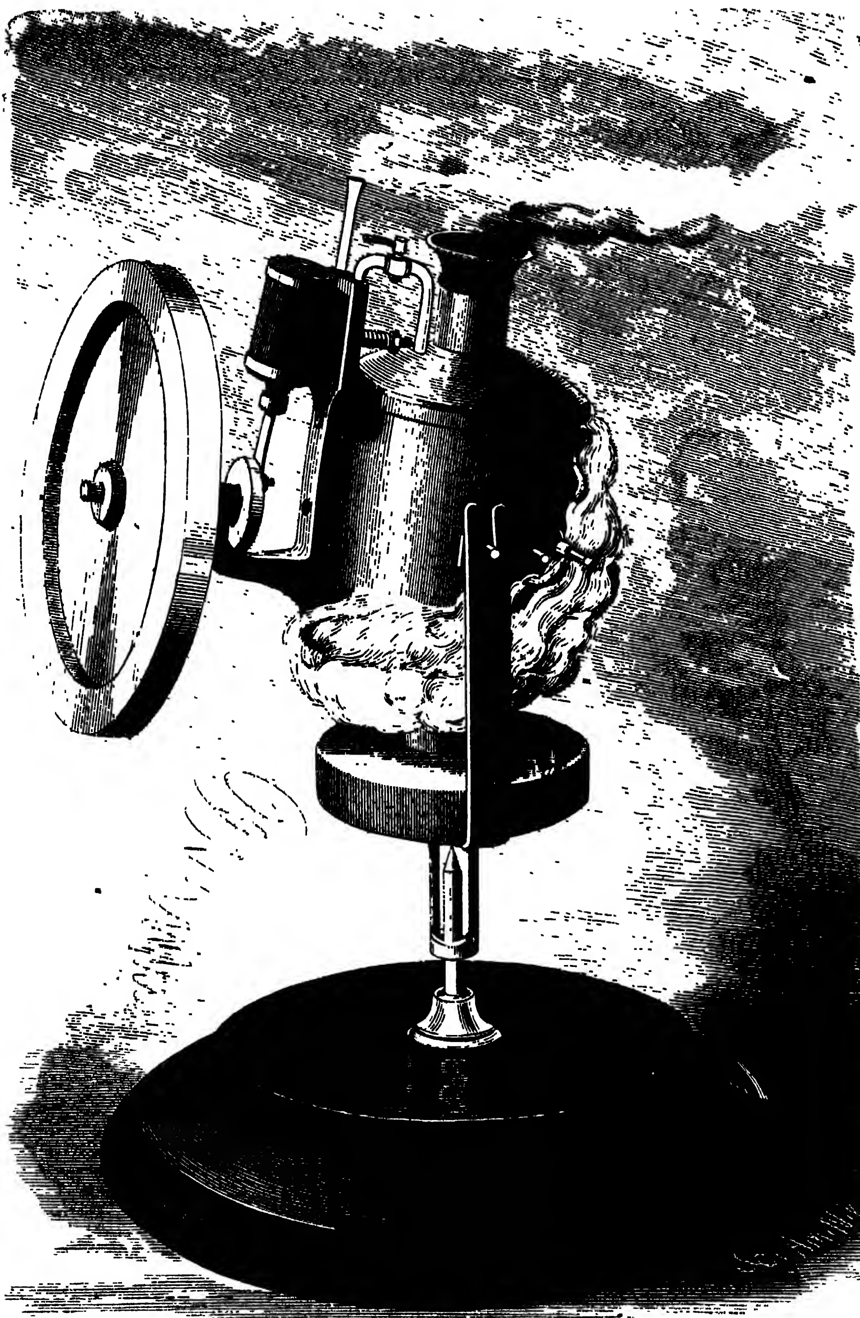
Pneumatic Gyroscope having Continuous Action.

the other power-propelled gyroscopes, and needs only a reactionary jet of steam or some other slight force to keep up the rotation around the vertical pivot, and thus render the action of the instrument continuous.

AN ELECTRICAL GYROSCOPE.

To render the operation of the gyroscope as nearly con-

Fig 17.



Steam Gyroscope.

tinuous as possible, so that its movements may be more thoroughly studied, electricity has been applied as a motive agent.

The gyroscope illustrated in Plate I. (frontispiece) and in Fig. 18 has a weighted base piece, from which projects a pointed standard that supports the moving parts of the instrument. The frame, of which the electro-magnets form a part, has an arm in which is fastened an insulated cup, that rests upon the point of the standard. One terminal of the magnet coil is connected with this cup, and the other terminal is connected with the yoke connecting the cores of the two magnets.

To the top of the yoke is secured a hard rubber insulator, which supports a current-breaking spring arranged to touch a small cylinder on the wheel spindle twice during each revolution of the wheel.

The wheel, whose plane of rotation is at right angles with the magnet cores, carries a soft iron armature, which turns very near the face of the magnet, but does not touch it. The armature is arranged in such relation to the contact surface of the current-breaking cylinder that twice during each revolution, as the armature nears the magnet cores, it is attracted, but immediately the armature comes directly opposite the face of the magnet cores, the current is broken, and the acquired momentum is sufficient to carry the wheel forward until the armature is again within the influence of the magnet.

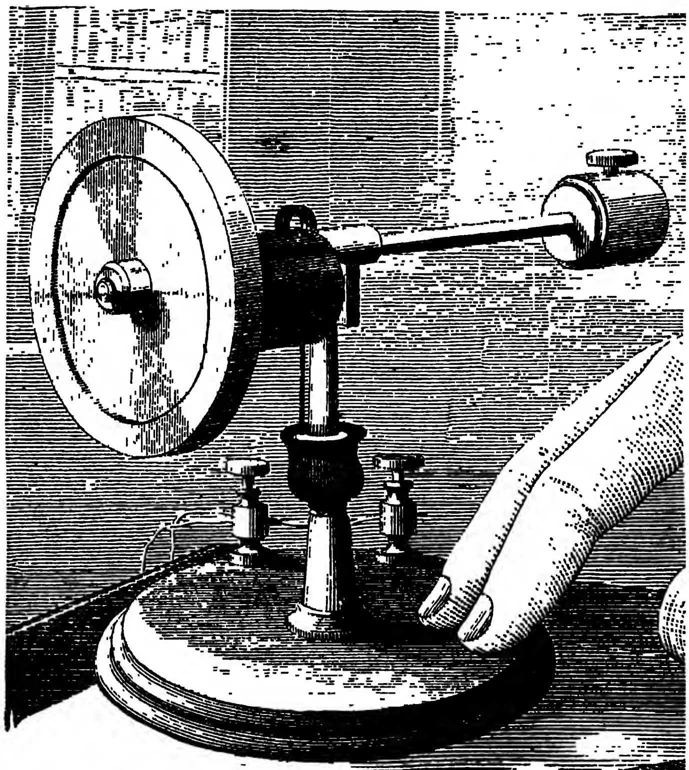
The current-breaking spring is connected with a fine copper wire, that extends backward as far as the pointed standard, and is coiled several times to render it very flexible, and is finally bent downward so as to dip in mercury contained in an annular vulcanite cup placed on the pointed standard near the base piece.

The base piece is provided with two binding posts for receiving the battery wires. One of the binding posts is connected with the pointed standard, and the other communicates by a small wire with the mercury in the vulcanite cup.

The wheel, magnet, and parts connected therewith are

free to move in any direction on the point of the standard. When two large or four small Bunsen cells are connected with the gyroscope, the wheel revolves with enormous velocity, and upon letting the magnet go (an operation requiring some dexterity), the wheel sustains not only itself, but also the magnet and other parts between it and the point of the standard, in opposition to gravity.

FIG. 18.



Electrical Gyroscope.

The wheel, besides rotating rapidly on its axis, sets up a slow rotation about the pointed standard in the direction in which the under side of the wheel is moving.

By attaching the arm and counterbalance shown in the engraving, so as to exactly balance the wheel and magnets on the pointed standard, the whole remains stationary. By overbalancing the wheel and magnets, the rotation of the ap-

paratus around the standard is in an opposite direction, or in the direction in which the top of the wheel is turning.

This gyroscope illustrates the persistency of a rotating body in maintaining its plane of rotation. It also exhibits the result of the combined action of two forces tending to produce rotations about two separate axes lying in the same plane, one force being gravity.

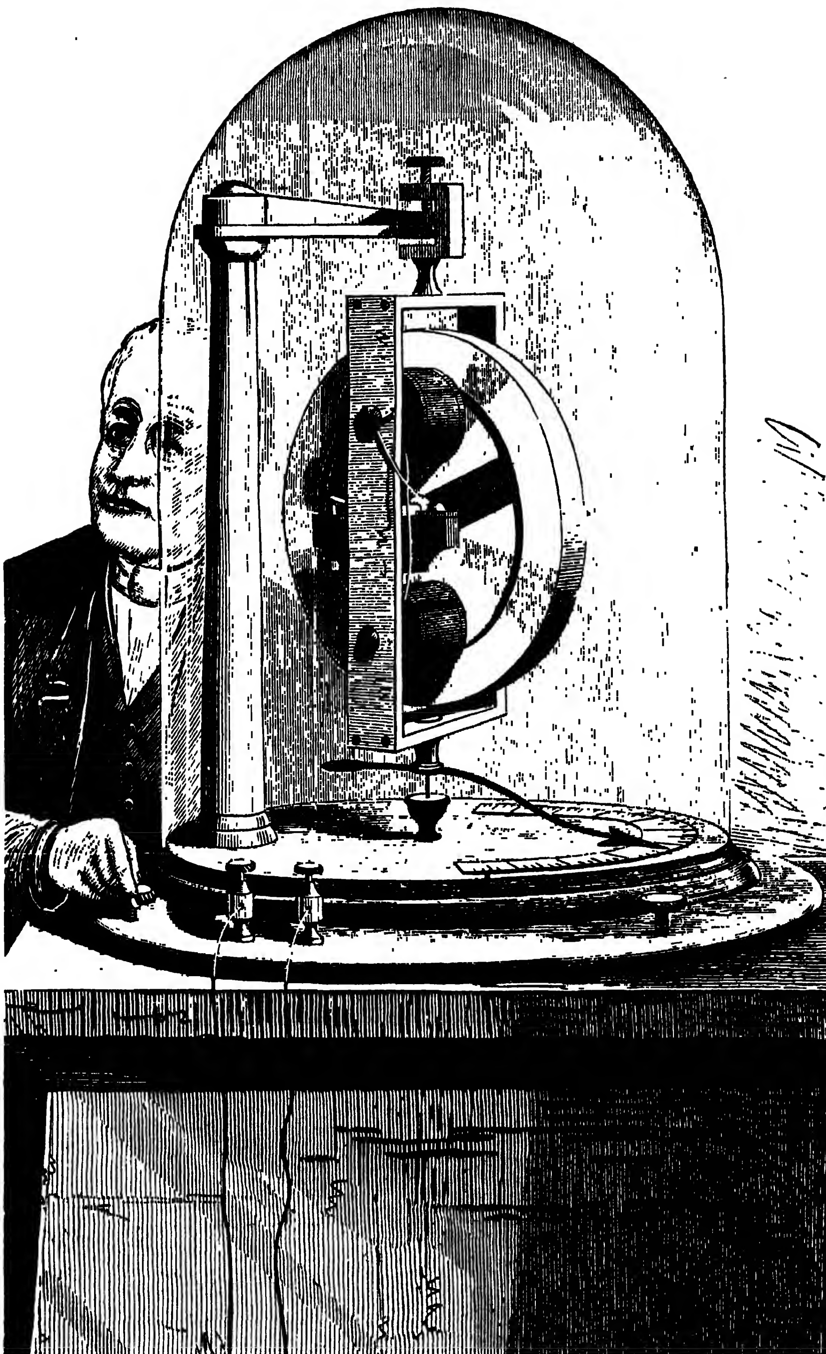
The rotation of the wheel upon its axis, produced in this instance by the electro-magnet, and the tendency of the wheel to fall, or rotate in a vertical plane about a second horizontal axis at right angles to the first, results in a tendency to continually rotate about a new horizontal axis intermediate between the two. The continual adaptation to this new axis implies rotation of the whole mass additionally around a vertical axis which is coincident with that of the pointed standard.

ELECTRICAL GYROSCOPE FOR SHOWING THE ROTATION OF THE EARTH.

Although the apparent displacement of the plane of vibration of the pendulum had long been noticed, it was not until the year 1852 that the fact was coupled with the diurnal rotation of the earth. In September of that year M. Foucault, the distinguished French physicist, suspended a ball, by means of a fine wire, from the dome of the Pantheon at Paris, and for the first time in the history of the world made visible the rotation of the earth. The pendulum thus formed, after receiving an impulse, vibrated for many hours, and preserved its plane of vibration while the earth slowly turned under it. This splendid experiment was subsequently repeated at the Capitol at Washington, and at other places.

Soon after the pendulum experiment, Foucault, to illustrate the same thing, constructed a gyroscope which was a modification of Bohnenberger's machine. This gyroscope received a rotating impulse from the hand of the operator, and the momentum of the disk was depended on to continue the rotation for a sufficient length of time to exhibit the movement of the earth.

Fig. 19.



Gyroscope for showing the Earth's Rotation.

To furnish a more practicable means of making visible the diurnal movement of the earth, the action of the gyroscope is made continuous by applying electricity as a propelling power.

In Fig. 19 (which represents the machine arranged for the purpose named) the rectangular frame which contains the wheel is supported by a fine and very hard steel point, which rests upon an agate step in the bottom of a small iron cup at the end of the arm supported by the standard.

The wheel spindle turns on carefully made steel points. Upon the spindle are placed two cams—one at each end—which operate the current-breaking springs.

The horizontal sides of the frame are of brass, and the vertical sides are iron. To the vertical sides are attached the cores of the electro-magnets, and the wheel is provided with two armatures—one on each side—which are arranged at right angles to each other. The two magnets are oppositely arranged in respect to polarity, to render the instrument astatic.

An insulated stud projects from the middle of the lower end of the frame to receive an index that extends nearly to the periphery of the circular base piece and moves over a graduated semicircular scale. An iron point projects from the insulated stud into a mercury cup in the center of the base piece, and is in electrical communication with the platinum-pointed screws of the current breakers. The current-breaking springs are connected with the terminals of the magnet wires, and the magnets are in electrical communication with the wheel-supporting frame.

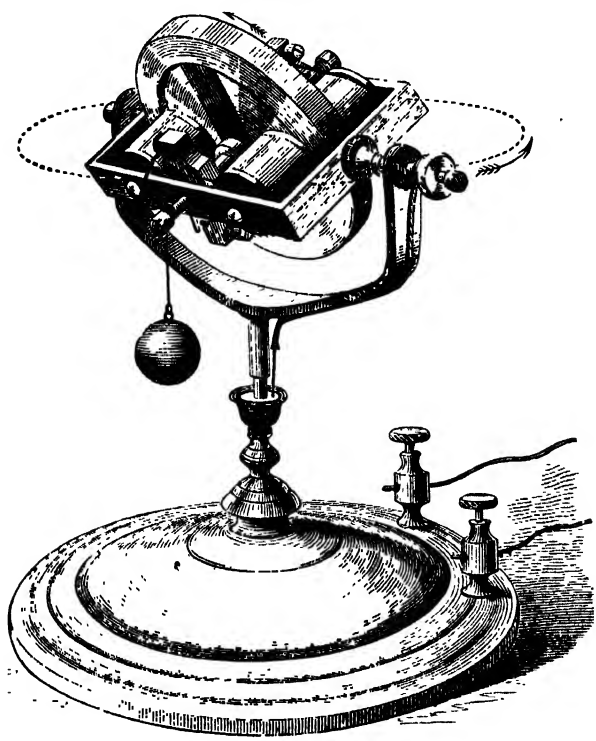
One of the binding posts is connected by a wire with the mercury in the cup, and the other is connected with the standard. A drop of mercury is placed in the cup that contains the agate step, to form an electrical connection between the iron cup and the pointed screw. The instrument is covered with a glass shade to exclude air currents, and the base piece is provided with leveling screws.

The current breaker is contrived to make and break the current at the proper instant, so that the full effect of the magnets is realized, and when the binding posts are con-

nected with four or six Bunsen cells, the wheel rotates at a high velocity.

The wheel will maintain its plane of rotation, and when it is brought into the plane of the meridian, the index will appear to move toward the right of a person facing northward with the index pointing northward in front of him. To a person in New York, therefore, the index seems to turn *toward the east*. To a person at the north pole, where

FIG. 20.



Electrical Gyroscope.

north is up and east is left, the hourly deviation is 15° *rightward*, or *westward*. At the equator there is, of course, no deviation.

It makes no difference whether the index points northward or southward, its apparent motion is always toward the right, thus affording visible evidence that the earth rotates.

The instrument thus described may be easily modified,

so as to illustrate other interesting phenomena of rotary motion.

By removing the index and point from the insulated stud at the lower part of the frame and unscrewing the supporting piece from the top of the frame, the frame may be suspended in a horizontal position upon pointed screws in a fork which is supported upon a vertical pivot, as shown in Fig. 20.

The pointed screw entering the insulated stud is itself insulated, and communicates, by an insulated wire, with mercury contained in an annular vulcanite cup on the fork-supporting pivot. One of the binding posts is connected with the pivot of the fork and the other communicates with the mercury in the vulcanite cup.

When the instrument is connected with a battery, the wheel revolves rapidly, and if undisturbed will remain in the position in which it was started. If a small weight, such as a key, be hung upon one of the pivot screws of the wheel spindle, the frame containing the wheel does not turn quickly on its pivots, as might be expected, or as it would if the wheel were not revolving, but the entire apparatus immediately begins to revolve slowly on the vertical pivot, while the weighted side of the frame descends almost imperceptibly. Transfer the weight to the opposite pivot, and while the wheel still revolves in the same direction, the apparatus will turn on the vertical pivot in the opposite direction.

By removing the weight from the pivot screw and turning the apparatus on the vertical pivot, the converse of what has just been described will result; that is, the wheel besides revolving on its own axis will turn in a plane at right angles to its plane of rotation.

If the apparatus be turned on the vertical pivot in the opposite direction, the rotation of the wheel on its new axis will be reversed, and by oscillating the apparatus on the vertical pivot the wheel and frame will revolve rapidly on the pointed screws that support the frame.

The law controlling these movements is as follows: "Where a body is acted upon by two systems of forces,

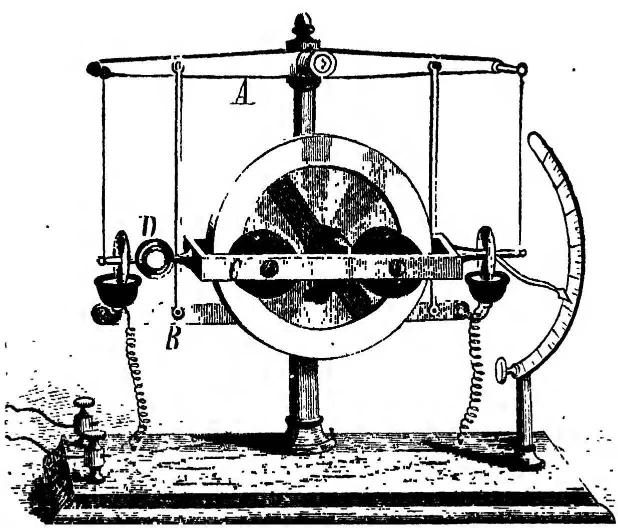
tending to produce rotations about two separate axes lying in the same plane, the resultant motion will be rotation abou a new axis situated in the same plane between the directions of the other two."

By means of this continuously operating gyroscope Dr Magnus' experiments showing some of the causes of devia- tion of projectiles may be exhibited.

EQUATORIALLY MOUNTED ELECTRICAL INDICATOR.

In Fig. 21 a gyroscope is shown which is suspended with the axis of the wheel-supporting frame, C, at right angles

FIG. 21



Electrical Indicator.

to the plane of the equator and parallel with the polar axis of the earth. The frame, C, is suspended by silk threads from studs that project from the beam, A. Two vulcanite mercury cups are supported by the beam, B, in position to make an electrical connection with the disks on the axes of the frame, C. These cups are connected by a spirally coiled wire with the binding posts that receive the battery wires. The beams, A, B, are connected by rods, so that when it is desired to adjust the instrument, the parts will maintain their proper relation.

Upon one of the axes of the frame, C, there is an index that moves in front of the scale of degrees. Upon the other axis there is a small mirror, D, for receiving a beam of light and projecting it on a screen. By this arrangement a very long index is secured without additional weight.

The instrument as represented in the engraving is adjusted for the equator. In New York the axis of the wheel-supporting frame would have to be adjusted at an angle of 40° 41′ with the horizon.

The instrument shown in the engraving should, when the axis of the frame, C, is adjusted equatorially, indicate 15° motion per hour in any latitude.

The arrangement of the wheel, the commutator, and connections is substantially the same in this instrument as in the one previously described.

BURSTING OF FLY-WHEELS BY GYROSCOPIC ACTION.

The theory of the bursting of fly-wheels, which has been accepted in the majority of cases, is that the centrifugal force due to a high velocity overcomes the cohesion of the particles of the material of which the wheel is composed.

Of course this explanation is entirely inadequate when applied to a wheel whose strength is sufficient to resist any tendency to fly to pieces from purely centrifugal force under the conditions of its use; but of the fact that such wheels burst no evidence is needed, and some cause other than centrifugal force must be assigned for the bursting.

Supposing the fly-wheel to be perfectly balanced and without defects in material or design, it may be driven without danger at any velocity usually considered within the limit of safety, so long as it continues to rotate in a plane at right angles to its geometrical axis. And it may be moved in the plane of its rotation or at right angles to it, that is, in the direction of the length of the shaft, without creating any more internal disturbance than would result from moving it in the same way while at rest. But when a force tending to produce rotation at right angles to the plane of the wheel's rotation is applied, the effect will be

Fig. 22.

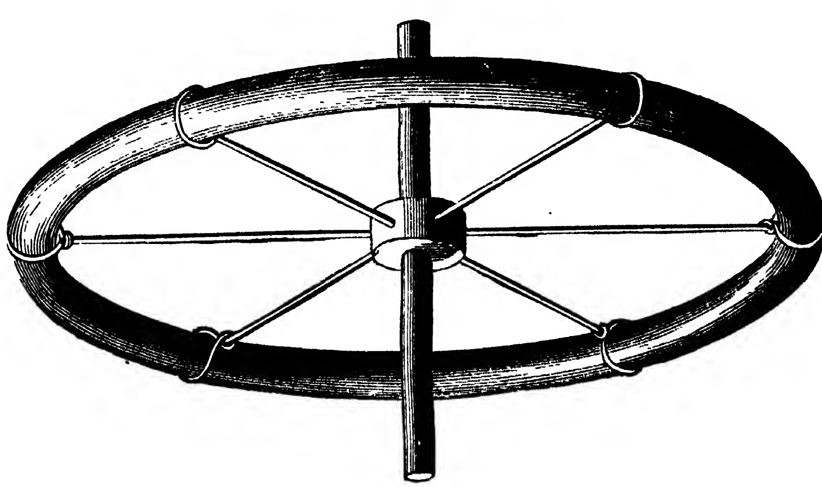


Fig. 23.

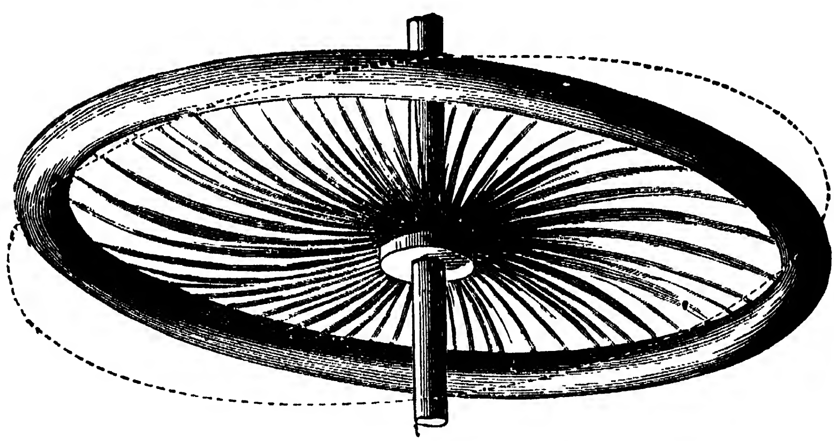
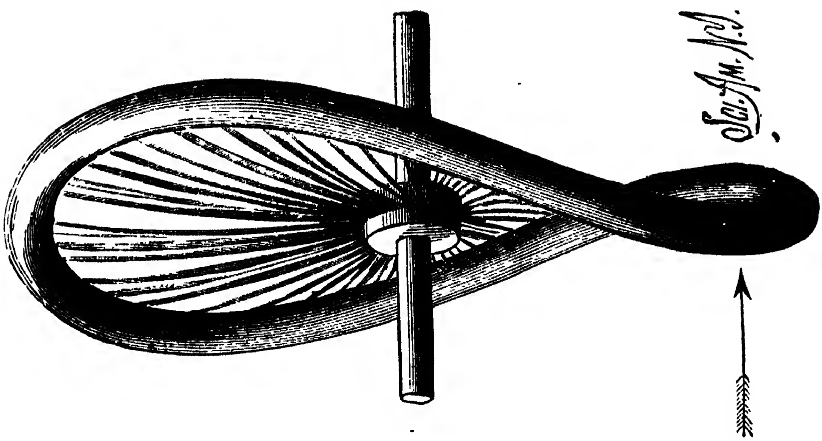


Fig. 24.



Flexible Fly-Wheel.

vastly different, and the result will be a tendency to rotate about a new axis between the other two, and the centrifugal strain upon the wheel is supplemented by a twisting strain, which is an important but generally unnoticed factor in the destructive action.

To bring this idea to a practical application, the shaft and fly-wheel of a high-speed engine may be taken as an example. Let the wheel be correctly designed, well made, and well balanced, and if its shaft is properly lined and supported in rigid journal boxes, the wheel will perform its office without danger of bursting; but support the same wheel and shaft upon weak plummer blocks, and allow one or both of its journals to move laterally at every stroke of the engine, or even less frequently, and a disturbing element will have been introduced which will strain the wheel laterally, and which, together with centrifugal force, will effect molecular changes in the structure of the iron, and the result will be that if the wheel is not immediately broken it finally becomes weakened, so that it will yield to the forces that tend to destroy it.

Any wheel whose axis is swung in a plane at right angles to its plane of rotation, either occasionally and irregularly or frequently and regularly, tends to turn laterally on an axis between that of the normal rotation and that of the extraneous disturbing force. This tendency exists in ordinary wheels, although not visible The engraving shows a flexible wheel, which clearly exhibits the effects of these disturbing forces. The rim is of rubber, the spokes of spring wire, and when the wheel is revolved very rapidly and moved in a plane parallel with its plane of rotation, no disturbance results, and no effect is produced by moving it at right angles to its plane of rotation; but when the wheel is turned even slightly on an axis at right angles to its geometrical axis by swinging the shaft laterally, the rim, while preserving its circular form, inclines to the plane of the rotation of its shaft, bending the spokes into a concave form on one side of the hub and convex on the other, showing the effects of the disturbing force on the figure of the wheel, as in Fig. 23.

When the disturbing force is rhythmical, lateral vibrations and wave motions are set up in the rim, which are out of all proportion to the extraneous force applied.

From this experiment it is evident that the lateral swinging of the shaft of a fly-wheel (for instance when its journal boxes are loose, or when the frame of the machine of which the fly-wheel forms a part is yielding) tends to weaken the wheel even when the lateral movement is slight; and where it is great, as when the shaft is broken, the twisting effect is correspondingly great, and the wheel or its support must yield.

No rotating machines are more subject to bursting than grindstones, and generally no rotating bodies of equal weight are mounted upon such small shafts or on such weak supports. The suspended ones are especially liable to the destructive action above described, as their frames are generally far too weak.

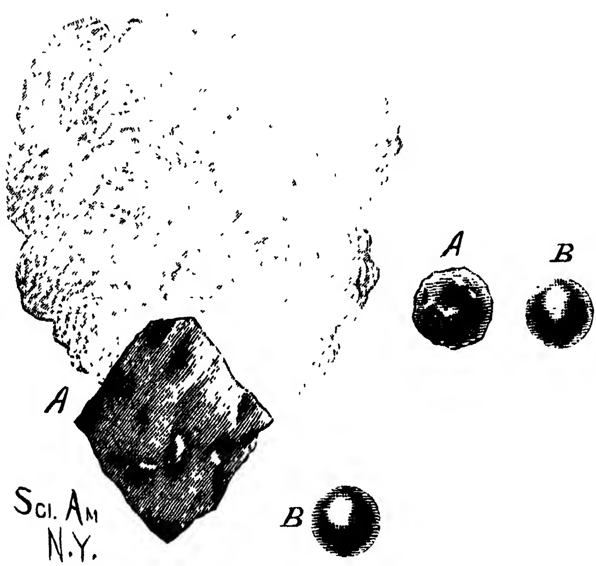
Fig. 24 illustrates the effect of a lateral blow on the rim of a fly-wheel. Of course the effect is much exaggerated in the flexible wheel, but it shows the form taken by the rim under a blow, the blow producing a much greater effect on the wheel while in motion than when at rest.

CHAPTER IV.

FALLING BODIES—INCLINED PLANE—THE PENDULUM.

"In a vacuum all bodies fall with equal rapidity." This is the first law of falling bodies. The well known guinea and feather experiment is a demonstration of this law. The

FIG 25.



Effect of the Resistance of Air on Falling Bodies.

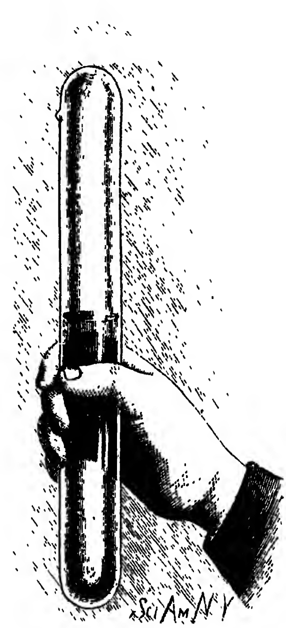
heavy body and the light one being dropped simultaneously in a tube deprived of air, reach the bottom at the same instant.

The converse of this experiment is illustrated in Fig. 25. In this case the retardation caused by the resistance of the air is clearly shown. A bunch of very loose cotton wool is attached to a small piece, A, of tin foil, and the cotton thus arranged is dropped simultaneously with the lead bullet, B. As would be expected, the bullet reaches the ground in about half the time required for the descent of the cotton.

By rolling the cotton into a compact ball and inclosing it in the tinfoil, the surface exposed to the air will be very much diminished, and when the experiment is repeated with the cotton thus diminished in bulk, it is found that the two bodies fall with nearly equal rapidity.

The water hammer shown in Fig. 26 demonstrates that in a vacuum liquids fall like solids, without being broken up or divided. The water hammer consists of a glass tube half filled with water, which is boiled to expel the air, the tube being afterward sealed. When the tube is inverted, the water falls in a body, striking the opposite end of the tube, producing a sharp clink.

FIG. 26.



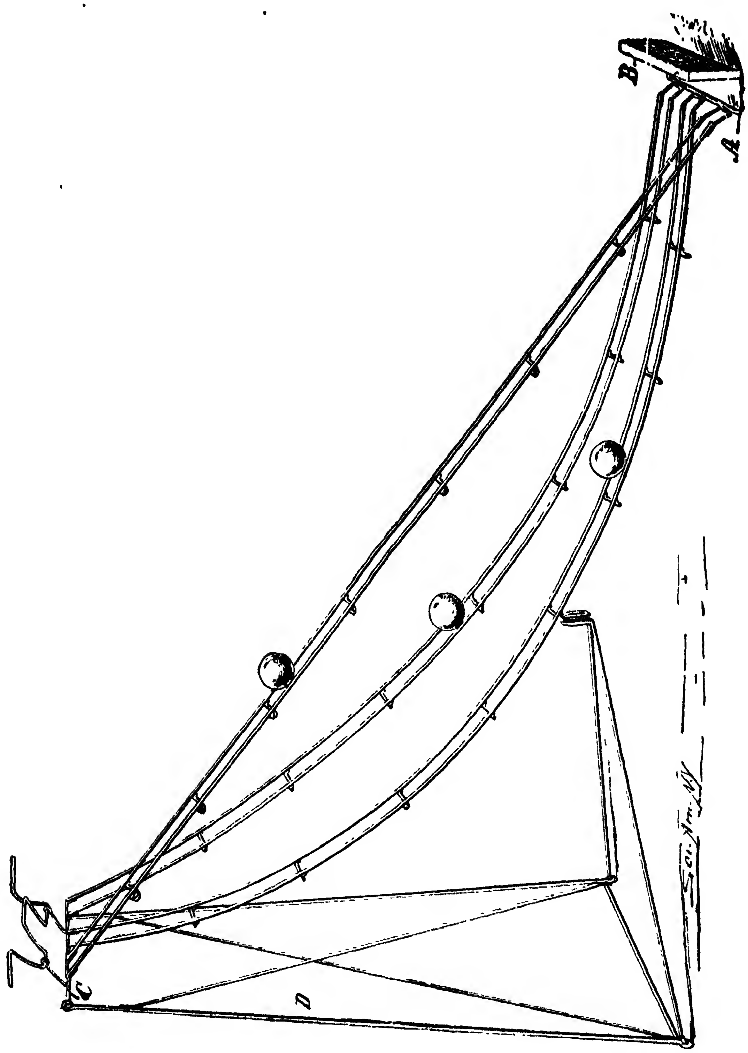
Water Hammer.

SWIFTEST DESCENT APPARATUS.

The descent of a falling body along an inclined plane is governed by the same law that controls the fall of free, unimpeded bodies, *i. e.*, "the spaces traversed are proportional to the squares of the times of descent." The law does not apply to the descent of a body along any curved path. A body descending a concave path will be accelerated most at the beginning of its fall. A body descending a convex path will start slowly, and will be increasingly accelerated as it approaches the end of its travel.

Three cases are here considered: First, that of a body rolling down an inclined plane; second, that of a body descending a concave circular curve; and third, that of a body descending a cycloidal curve. In the case of the inclined plane, if the body falls two feet in one second, it will fall eight feet in two seconds, eighteen feet in three seconds, and so on. In the case of the concave circular curve, the fall of the body will be accelerated rapidly at the start, and

the body will reach the point of stopping quicker than the body on the inclined plane, although it travels over a longer distance. In the case of the cycloidal curve, the body acquires a high velocity at once, as its path at the beginning



27.

De ppa

is practically vertical. This curve has been called the curve of swiftest descent, as a falling body passes over it from the point of starting to the point of stopping in less time than upon any other path, excepting, of course, the vertical.

The cycloid has another property, in virtue of which it

has been called the isochronal curve. A body will roll down this curve from any point in its length to the point of stopping in exactly the same time, no matter where it is started. For example, if it requires a second of time for a ball to roll from the upper to the lower end of the curve, it will also take one second for a ball to roll from the center of the curve to its lower end.

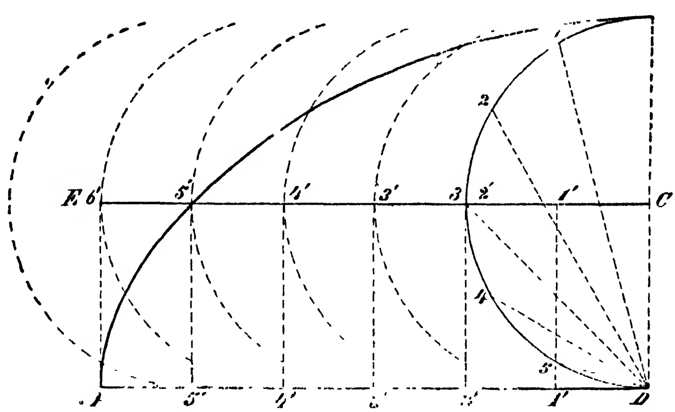
Apparatus for illustrating these principles is shown in Fig. 27. It does not differ much from the ordinary apparatus used for the same purpose. It is, however, made entirely of wire, and is arranged to fold, so that it occupies little space when not in use. The rails of the tracks are formed of one-eighth inch brass wire. These rails are connected by curved cross pieces having ends bent at right angles and soldered to the under surface of the rails. The lower ends of the rails are connected by angled wires with a cross bar, A, which is bent forward, then upward, to receive the board, B, forming the stop for the balls. The upper ends of the rails are connected by angled wires with a cross bar, C, which receives the loops of the wire leg, D. To the leg is jointed a brace which hooks over one of the cross pieces of the middle track.

To the upper cross bar are soldered wire eyes, supporting a wire bent so as to form three cranks for holding the balls, and releasing them all together. The rods of which the tracks are formed are about three feet long. The cycloid track is made first, the others being cut off to match. A method of laying out the cycloid curve is shown in Fig. 28. At the end of the base line, A D, draw the line, C D, perpendicular to A D. Describe a generating semicircle (in this case of nine inch radius) tangent to A D, at D. Through its center draw the line, E C, parallel to the base line. Divide the semicircle into any number of equal parts —six for example—and lay off on A D and E C distances equal to the radius C D × 3·1416, and divide A D and E C into six equal parts, C 1′, 1′, 2′, etc., equal to the divisions of the semicircle; draw chords, D 1′, D 2′, etc. From points 1′, 2′, 3′, etc., on the line, C E, with radii equal to that of the generating semicircle, describe arcs.

From points 1′, 2′, 3′, 4′, 5′, on the line, D A, and with radii equal successively to the chords, D 1, D 2, D 3, D 4, D 5, describe arcs cutting the preceding, and the intersections will be the points of the curve required. Through these points the curve is drawn, and the wires for the cycloid track are bent so as to conform to this curve. The track, when completed, must sustain the same relation to a horizontal line as the curve in the diagram sustains to the base line, A D.

Another method of describing a cycloid is to fix a pencil in the edge of a disk and roll the disk on a level surface, without slipping, with a pencil in contact with a smooth board

FIG. 28.



Method of Describing the Cycloid.

or a piece of paper, the curve being started with the pencil at the lowest point or in contact with the base line.

A ball is supported at the upper end of each track by the cranked wire, and when the three balls are liberated simultaneously by quickly turning up the cranked wire, it will be found that the ball on the cycloid reaches the point of stopping first, the ball on the circular curve coming next, the ball on the inclined plane being slowest of all.

If two cycloidal tracks be placed side by side, it will be found by trial that a ball started from the middle or at any point between the ends of one of the tracks will reach the point of stopping no sooner than the ball started at the top

of the other track. In fact, if the tracks are accurately made, both balls, if started simultaneously, will reach the bottom at the same time.

DROPPED AND PROJECTED BALLS.

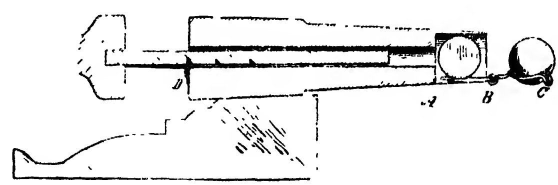
Although there is no shorter or quicker route for the descent of a falling body than that of a plumb line, it has been shown that a body projected horizontally with whatever force, and describing a long trajectory, will reach the earth in exactly the same time as another similar body simply dropped from the same height. There are many simple and ingenious devices for demonstrating this fact. If the experiment could be brought within convenient compass for observation, nothing would be better for the purpose than an ordinary gun, with powder as the propelling power, but this is of course out of the question. It is therefore necessary to resort to apparatus which may be used in an ordinary room, so that both projected and falling ball may be seen and heard. The apparatus is still a gun, but a very harmless and inexpensive one. It is a modified "Quaker gun," a well known toy used for shooting marbles.

Fig. 29 is a perspective view of the gun, showing it immediately after its discharge, and Fig. 30 is a longitudinal section showing the gun ready to be discharged. The gun consists of a wooden barrel chambered at the muzzle to receive the marble and provided with a rod attached to the breech piece, extending into the barrel and arranged to be propelled forward by a strong elastic rubber cord stretched over the breech piece, with its ends nailed to the sides of the gun barrel.

Two changes only are required to adapt the gun to scientific use. First, the notching of the rod passing through the barrel and the application of the trigger, D, for engaging the notches, and second, the support for the falling ball at the muzzle of the gun. The trigger, D, is merely a strip of sheet metal pivoted to the end of the barrel by an ordinary screw. In the muzzle of the gun at the under side is formed a slot, A, and in the end of the gun on opposite sides of the slot are inserted eyes, B. In these eyes is jour-

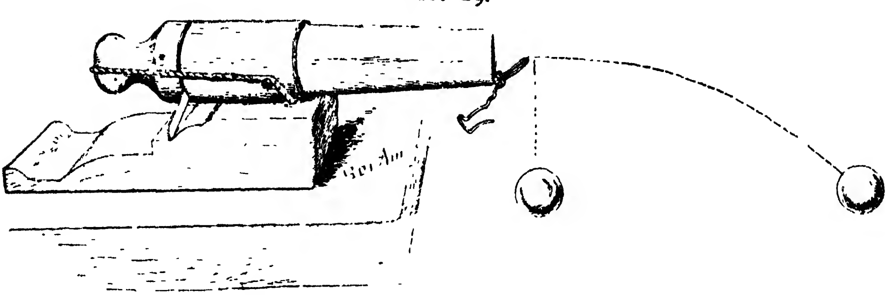
naled a wire support, C, which holds the ball to be dropped, at one side of the muzzle and out of the path of the projected ball. The wire support, C, forms a lever, one end of which projects into slot in the barrel and is held by the ball in the muzzle. When the rod in the barrel is liberated by pulling the trigger, D, the ball in the muzzle is projected, thereby releasing the wire support, which immediately turns and allows the other ball to drop. It will be noticed that both balls reach the floor at exactly the same time, without regard to the amount of force applied to the projected ball.

FIG. 30.



Longitudinal Section of Gun.

FIG. 29.



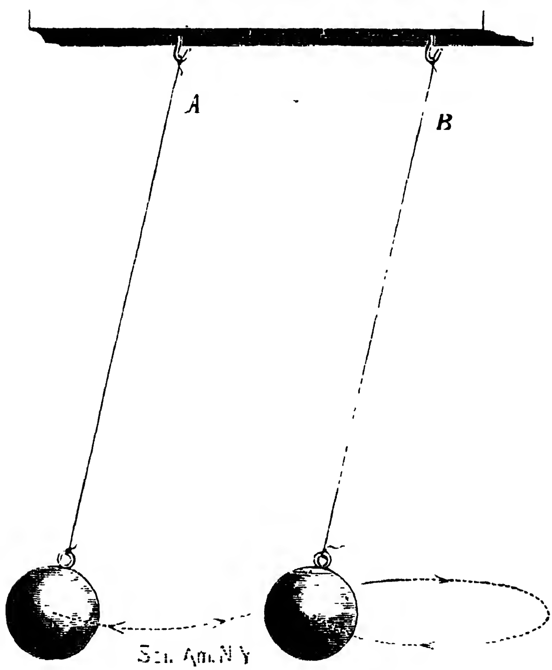
Dropped and Projected Balls.

The falling ball is impelled by the force of gravity only. The projected ball is acted upon by two independent forces—the force of gravity, which draws it toward the earth, and the projecting force, which tends to move it in a horizontal line. The projecting force is concerned only in carrying the ball horizontally forward, and does not in any way interfere with the action of gravity, but gravity brings the ball gradually nearer the earth, until it finally strikes. The gun in this experiment should, of course, be fired over a level plane.

THE PENDULUM.

A simple pendulum, which is a purely theoretical thing, is defined as a heavy particle suspended by a thread having no weight. The nearest possible approach to a simple pendulum is a heavy body suspended by a slender thread, as shown at A in Fig. 31, and although this is known as a compound or physical pendulum, its action corresponds very nearly with that of the simple pendulum. In the present

FIG. 31.



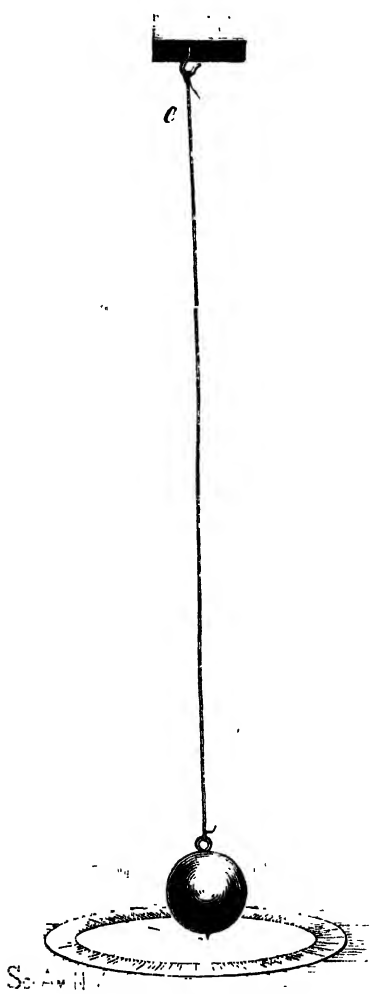
Oscillating and Conical Pendulums.

case the pendulum consists of a heavy bullet or lead ball suspended by a fine silk thread. This pendulum, to beat seconds in the latitude of New York, must be 39·1012 inches long. That is the distance between the point of suspension and the center of oscillation of the weight. This length varies in different places; *e. g.*, at Hammerfest, in Norway, it is 39·1948, and at St. Thomas, one of the West India islands, 39·0207.

A seconds pendulum is one that requires one second for a single swing, or two seconds for a complete to-and-fro

excursion. The distance through which the suspended weight travels in one swing is the amplitude of the pendulum. Galileo's discovery of the law of the pendulum in 1582 is a matter of common knowledge. He observed the regularity of the swinging of a lamp suspended from the roof of the cathedral of Pisa, and noticed that, whetever the arc of vibration, the time of vibration remained the same. He also determined the law of the lengths of pendulums by experiment. He found that, as the length of the pendulum increased, the time of vibration increased, not in proportion to the length, but in proportion to its square root. For example, while in New York it requires a pendulum 39·1012 inches long to beat seconds, the length for two seconds would be 156·4048 in. The length of a pendulum for any required time is found by multiplying the length of a seconds pendulum in inches by the square of the time the pendulum is to measure. In the above example, 39·1012 inches is the length of the seconds pendulum. Two seconds is the time to be measured. $2^2 = 4$. Therefore $39{\cdot}1012 \times 4 = 156{\cdot}4048$, the length of the two seconds pendulum. It is found that, barring the resistance of the air, all materials act alike when used for the weight of a pendulum. This is one proof of the uniformity of the action of gravitation on all substances.

FIG. 32.

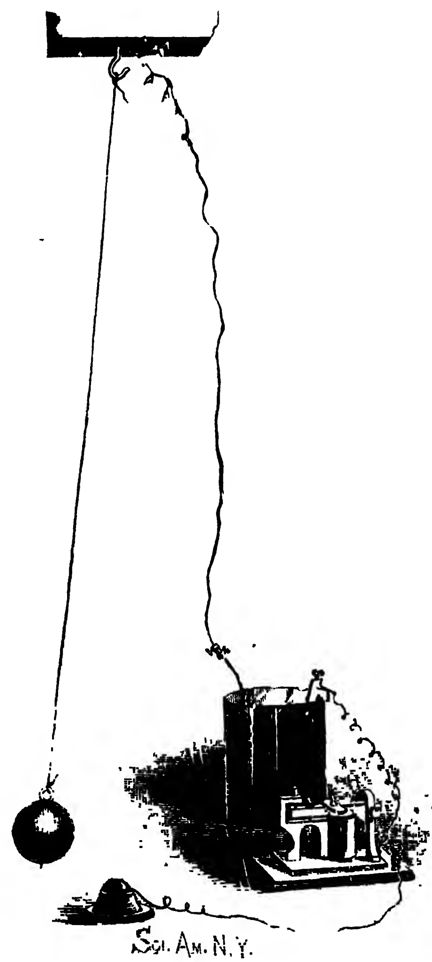


Foucault's Experiment.

In Fig. 31, at B, is shown a conical pendulum. It differs

from the pendulum A only in the manner in which it is used; whereas the pendulum A is made to swing to and fro in a vertical plane, the pendulum B is started in a circle, as indicated by the dotted line. It is found by comparison that the pendulum B completes its circular travel in the same time that pendulum A requires to complete one to-and-fro vibration. The conical pendulum derives its name from the figure it cuts in the air.

FIG. 33.

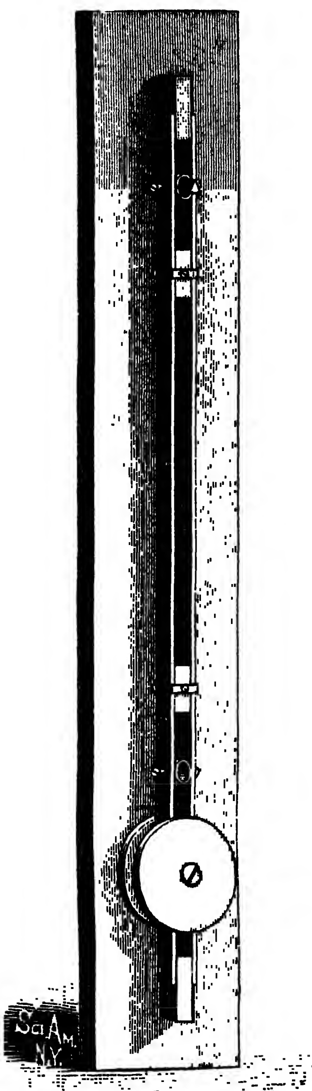


Pendulum with Audible Beats.

The pendulum has been used to determine the figure of the earth, also to show the earth's rotation. Foucault's celebrated experiment at the Pantheon at Paris consisted in vibrating a pendulum having a period of several seconds over the face of a horizontal scale While the pendulum preserved the plane of its oscillation, the scale indicated a slow rotation. This experiment may be repeated easily on a small scale in the manner illustrated in Fig. 32. The ball, which must be a heavy one, is suspended by a very fine wire of considerable length, say from forty to fifty feet. It must be started very carefully to secure the desired result. To start it, a fine wire is tied around the equator of the ball. To this wire is attached a stout thread, by means of which the ball is drawn one side and held there until the pendulum is perfectly quiescent. The pendulum is then released by burning the thread.

In the course of a few minutes there will appear to be a slight change of its plane of vibration. The case is like that of the gyroscope already described. The plane of vibration remains really constant, but the rotation of the earth causes an apparent twisting of the plane. If the experiment be performed in the United States, and the plane of vibration be north and south at first, the northern limit will soon swing toward the right, as viewed from the south.

Fig. 34.



Kater's Reversible Pendulum.

A pendulum capable of producing audible beats is often desirable. Fig. 33 shows a simple, well known arrangement for producing audible beats by the aid of a telegraph sounder. The ball, in this case, is suspended by a fine wire. The under side of the ball is provided with a platinum point. A mercury globule is held by an iron cup in the path of the platinum point, and the pendulum, mercury, and sounder are in the battery circuit. By this arrangement an electrical contact is made for each swing of the pendulum, and the sounder is made to click each time the circuit is closed.

By means of Kater's reversible pendulum, the length of a simple pendulum having the same time of oscillation as the compound pendulum may be accurately determined.

In Fig. 34 is shown a slightly modified form of this pendulum, in which the rod is formed of two parallel bars of wood, separated by blocks at the ends and provided with two swiveled cylindric rings, be-

tween which are placed two adjustable lead weights, held in place by crossbars secured to the weights by screws, and extending over the edges of the wooden bars. Below the lower swiveled ring are clamped lead weights, one upon either side of the bar, with a screw extending through one weight into the other. These weights are cheaply made by casting lead in small blacking box covers.

This pendulum is suspended upon a knife edge projecting from a suitable support, and the weights between the bars are adjusted until the time of vibration is the same for either position of the pendulum, it being reversed and oscillated first upon one of its rings as a center, then upon the other, until the desired adjustment is secured. Then the distance between the bearing surfaces of the rings will be the length of a simple pendulum which would vibrate in the same time as the compound pendulum.

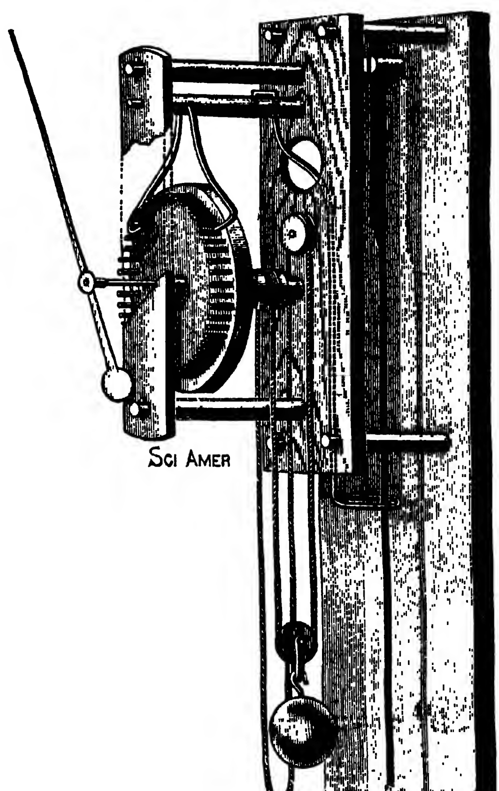
MEASUREMENT OF TIME BY THE PENDULUM.

The application of the pendulum to the measurement of time dates from 1658. In that year Huyghens applied it to clocks. Singularly enough, this has proved to be the only practical use of any importance to which the pendulum could be adapted. The fact that millions of clocks have been made which depend on the pendulum for regulation proves the great value of Huyghens' invention.

A simple model, showing the application of the pendulum to clocks, is illustrated in Fig. 35. It is readily made, and serves to show how the pendulum acts in the regulation of a clock, and is useful for measuring seconds in experimental work. The frame is made entirely of hard wood. The three parallel plates are connected by wooden studs. The wooden arbor of the scape wheel is provided with steel wire pivots, the outer one being prolonged beyond the front plate to receive the second hand. The scape wheel consists of a disk of wood about three inches in diameter, provided with a circular row of steel pins, uniformly spaced and projecting from the face of the disk parallel with the arbor. With a disk of the size given thirty pins will be sufficient, with a larger disk sixty pins may be used.

Above the scape wheel arbor there is a wooden roller furnished with steel wire pivots. In the roller is inserted a steel wire forming the escapement or crutch, the ends of the wire being bent inward to form pallets which engage the scape wheel pins in alternation. The rubbing surfaces of the pallets are flattened and polished and the ends are beveled. In the roller is inserted a wire which extends down-

FIG 35.



Application of the Pendulum to Clocks.

ward obliquely through a hole in the middle plate, and is finally bent into an oblong loop extending rearward. In a split stud in the back piece is inserted the flattened upper end of the pendulum rod. A small rivet passes through the upper extremity of the rod. and prevents it from slipping through the split stud. The rod passes through the

oblong loop above referred to, and is provided on its lower end with an adjustable weight of $1\frac{1}{2}$ to 2 pounds.

The scape wheel arbor is provided with a circumferential V-shaped groove forming a very small pulley for receiving the driving cord. Upon the middle plate above the arbor is fixed a circular block having a deep V-shaped circumferential groove for receiving and holding the endless driving cord, which passes round the arbor and grooved block as shown, and also passes around the pulley block attached to the weight. It is necessary to have the V-shaped grooves very deep and very narrow to enable them to pinch the driving cord. To insure uniformity in the action of the cord and weight, it is advisable to place in the second loop of the cord a pulley and connect with it a very light weight. When the driving weight has nearly run down, the cord may be pulled upward over the grooved block and fastened. The pendulum rod is made very thin and flexible at the upper end by hammering. The rod is made of wire of sufficient diameter to prevent springing by the action of the escapement, and the pendulum bob is adjustable. The distance between the center of the bob and the split stud is 39·1012 inches.

The motion of the pendulum is a result of the downward pull of gravity and the restraint of the pendulum rod. It is forced by gravity to move until the lowest point of its arc is reached, when the momentum acquired carries it forward and upward, in opposition to the earth's attraction, until its momentum is overcome by gravity, when it stops and is again drawn down by gravity, causing it to return to the lowest part of its arc and repeat the movement just described, but in the opposite direction. But for friction of the air and of its parts, the pendulum would swing on indefinitely without the propelling power.

The isochronism of the pendulum is perfect only when its amplitude of vibration remains the same, or when it is arranged to move in a cycloidal path. It is impossible to maintain constantly the same amplitude of vibration, and it is difficult to cause the pendulum to describe a true cycloid. A very close approximation to isochronism is secured by

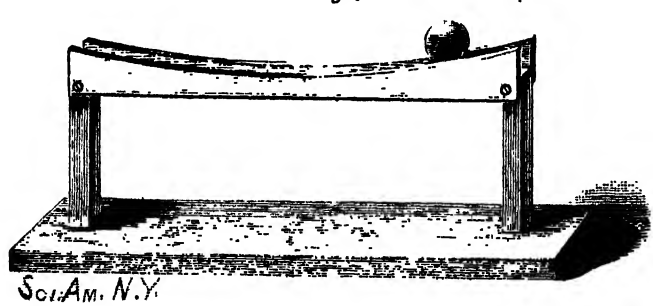
suspending the pendulum by means of a flat spring as above described and by limiting its swing to a very small arc.

The motion of a cycloid pendulum is very well illustrated by the cycloidal track and the ball shown in Fig. 36. The track is formed of steel bars smoothly finished, and the ball is of steel, hardened, ground, and polished, one of the kind used for ball bearings.

The period of oscillation of the ball rolling on the cycloid track is the same for all amplitudes. This may be readily proved by comparing two like instruments with the balls oscillating at different amplitudes.

A torsion pendulum is one that depends for its action upon the twisting and untwisting of an elastic suspension. The simplest pendulum of this class is the toy known as the

FIG. 36.



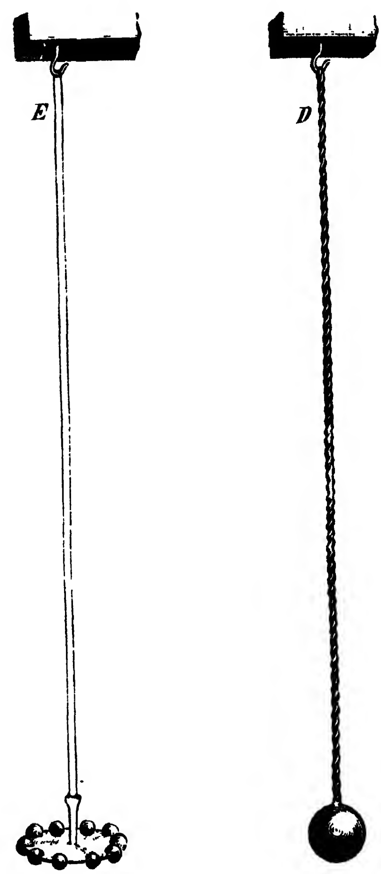
Cycloid Curve.

return ball. It consists of a wooden ball attached to the end of an elastic rubber cord. By grasping the free end of the cord and swinging the ball so as to cause it to roll in a circular path on the floor, the cord will be rapidly twisted. If, after twisting, the cord be fastened to a support, as shown in Fig. 37, it will be found that the ball will rotate rapidly by the untwisting of the cord. The momentum of the ball acquired during the untwisting will again twist the cord, but in the opposite direction. This pendulum will run more than an hour with a single winding. The period of such a pendulum, taken at random from a pile of return balls, was 1½ minutes, the rubber cord when not extended being about a foot long.

By means of apparatus similar to that shown in Fig. 38,

Coulomb determined the laws of the torsion of wires. The wire by which the weight is suspended is firmly secured to the hook, and the weight is provided with an index. The angle through which the index is turned from the position of rest is the angle of torsion. After turning the weight and releasing it, the elasticity of the wire returns it to the point of rest and the momentum of the weight carries it forward, twisting the wire in the opposite direction, until the weight reaches a point where the momentum of the weight is overbalanced by the resistance of the wire, when the wire again untwists, turning the weight in the opposite direction. These oscillations continue until the force originally applied is exhausted in friction. The oscillations within certain limits are very nearly equal.

FIG. 39. FIG. 37



Torsion Pendulums.

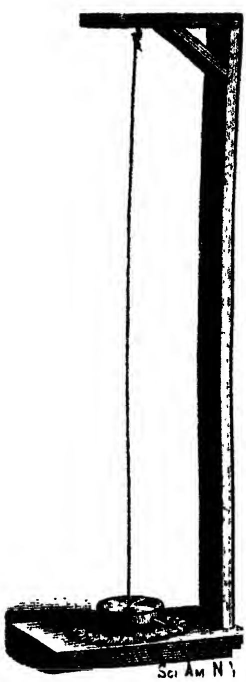
A torsion pendulum, with a bifilar suspension, is shown in Fig. 39. The wheel is formed of a disk of metal, with a series of split lead balls pinched down upon its edge. The wheel weighs $1\frac{1}{2}$ pounds. Its diameter is four inches. It has a double loop at the center for receiving the parallel suspending wires, which are $\frac{3}{8}$ inch apart and 5 feet long. No. 30 spring brass wire was used in this experiment. The period of the pendulum was five minutes.

The torsion pendulum has been successfully applied to clocks. Either of two results may be secured by its use. The time of running may be prolonged in proportion as the

the torsion pendulum is longer than that of an ordinary one, or the number of gear wheels required in the clock may be greatly reduced. Ordinary clocks constructed on this principle run a year with a single winding. Clocks have been made on this plan which would run for one hundred years.

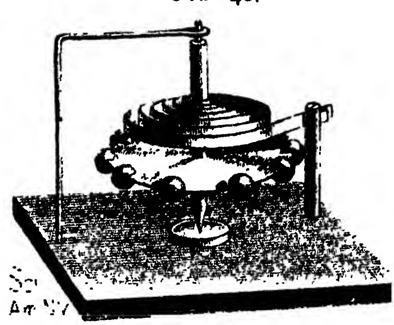
In the same year that Huyghens applied the oscillating pendulum to the clock, Hooke applied the spiral spring to the watch balance, thereby causing it to act as a pendulum.

FIG. 38.



Torsion Pendulum.

FIG. 40.



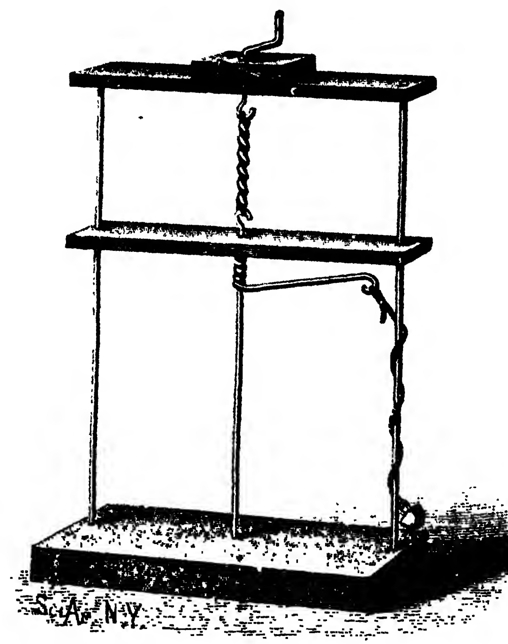
The Balance.

The principle of Hooke's invention is illustrated by Fig. 40. The apparatus here shown has a vibratory period of one second. The staff rests at the bottom in a small porcelain saucer and turns at the top in a wire loop secured to the base board. The disk on the staff is loaded at its periphery with lead balls. A large watch main spring or music-box spring is attached to the staff and to a fixed standard. The oscillation may be quickened by using a stiffer spring or by removing some of the balls.

In Fig. 41 is represented a model of a pendulum of recent invention which has been applied to clocks with some success.

Two cross bars are supported from the base by two wires. In the lower cross bar and in the base is journaled a wire having a hook at the upper end. This vertical wire carries a curved arm, to which is attached a thread having at its extremity a small weight, such as a button. The propelling power in this model consists of an elastic rubber band placed on the hook on the vertical rod, and received in a hook on the little crank shaft in the upper bar. The rubber band is twisted by turning the crank, and the crank is prevented from retrograde movement by the wire catch at the side of the bar.

FIG. 41.



Flying Pendulum.

As the arm is carried around by the power stored in the rubber band, the weight on the thread is thrown outward by centrifugal force. When it reaches one of the side rods, it wraps the thread several times around the rod, thus holding the arm until the thread is unwound by the action of the weight, when the arm describes another half revolution and the operation just described is repeated.

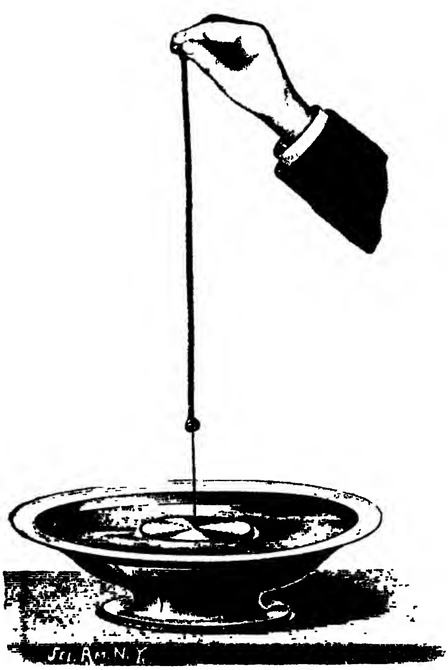
CHAPTER V.

MOLECULAR ACTIONS.

Cohesion and adhesion are forces which hold together *molecules or ultimate particles. Cohesion unites molecules of the same nature.* It is exerted strongly in solids, to a less degree in liquids, and very little in gases.

Heat causes the mutual repulsion of molecules, and thus diminishes the force of cohesion. Solids, when strongly heated, expand, liquefy, and finally pass into a gaseous state, if not chemically changed at the temperature reached, *e. g.*, wood, leather, etc. The tenacity, hardness, and ductility of bodies is due to cohesion.

FIG. 42.



A Demonstration of Cohesion.

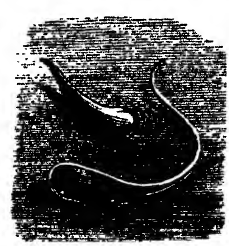
The force of cohesion in liquids may be demonstrated by suspending a disk by a delicate filament of elastic rubber, noting the extension of the rubber, then placing the disk in contact with a body of water, as shown in Fig. 42, finally drawing upon the rubber until the disk separates from the water. It is found that a considerable extension of the rubber is required to detach the disk. By a more delicate experiment, in which the disk is suspended from a scale beam, the force of cohesion may be accurately measured. It is found by this experiment that

the material of the disk has no influence on the result, but that the weight required to detach the disk varies with the nature of the liquid. The fact that the disk retains a film of water after separation from the body of water shows that the force of cohesion of the water is less than the force of its adhesion to the disk.

In solids cohesion is often manifested in different degrees in different parts of the same body. The body is then under strain. Examples of bodies in this condition are to be found among iron castings and in unannealed glass ware.

Prince Rupert's drops, or Dutch tears, show in a striking manner how a body under sufficient internal strain may contain within itself the elements of destruction. These drops have a long, oval form, tapering at one end to a point, which is more or less curved. They are made by dropping melted glass into water, thus suddenly cooling the glass and putting it under great strain.

FIG. 43.



Prince Rupert's Drops.

The larger part of the drop may be struck with a hammer without breaking; but on breaking off the point, thus relieving the strain at one place, the glass instantly flies into pieces. So complete is the destruction, that the fragments are often like fine sand.

The Bologna flask is of the same nature as the Prince Rupert's drops. It is an unannealed glass flask, having a very thick bottom, which is under great strain. The flask will receive a hard blow without breaking, and a lead bullet may be dropped into it without producing any effect, but on dropping into it a quartz crystal, or in some other way slightly scratching the inner surface of the flask at the bottom, the flask at once goes to pieces. The action may be compared to the destruction of a superstructure of masonry by weakening or destroying the keystone of the arch which supports it.

A common example of action of this kind is met with in lamp chimneys, which break without any apparent cause. Engineers often find glass water-gauge tubes which will

readily stand steam pressure, but which, when scratched even imperceptibly on the inner surfaces, will break.

Adhesion is the term applied to the attraction between the surfaces of two bodies. In the experiment illustrated by Fig. 42 the water adheres to the disk, and the force of adhesion in this case is superior to the force of cohesion as manifested by the molecules of the water. If the moistening of the disk by the water is prevented by lycopodium distributed on the surface of the water, there can be no adhesion.

FIG. 44.

Bologna Flask.

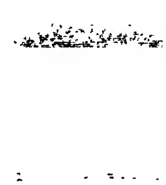
Two pieces of plate glass pressed firmly together adhere strongly. This experiment succeeds in a vacuum, showing that atmospheric pressure plays no part in holding the glasses in contact.

In the arts, examples of adhesion are found in glues, cements, and solders.

SURFACE TENSION.

The surface tension of liquids is manifested in various ways, notably in the formation of drops, as in rain, each drop becoming a perfect sphere Water sprinkled upon a surface it does not wet, for example, a dusty surface, or upon a surface covered with lycopodium, assumes spheroidal forms, as shown in Fig. 45.

FIG. 45.



Surface Tension exhibited in Water Drops.

A pretty illustration of cohesion and surface tension is shown in Fig. 46. A few drops of olive oil are placed in a suitable vessel, and into the vessel is carefully poured a mixture of alcohol and water having the same specific gravity as the oil. The oil will be detached from the bottom of the vessel, and will, in consequence of the cohesion of its particles, assume a spherical form. Another method of performing this experiment is to introduce the oil into the center of the body of dilute alcohol by means of a pipette. By careful manipulation a large globule of oil may be introduced in this way.

FIG. 46.

Oil Globule suspended in Equilibrium.

Liquids in large masses assume the form of the vessel in which they are contained, in consequence of the superior force of gravity.

From what has been said, as well as from what follows, it will be seen that liquids act as though they were inclosed in a tense superficial film. A glass tube pressed endwise into a body of mercury (Fig. 47) produces a deep depression before breaking the surface of the liquid. When a glass tube is presented in a similar way to the surface of water (Fig. 48), the effect is

reversed, the water attaching itself to the surface of the glass with such force as to spread and lift the water in the immediate vicinity of the wall of the tube. In tubes of large diameter, the height to which water is lifted is slight, but in capillary tubes the height is considerable.

Fig. 49 shows the effect of the size of the tube on the height to which the liquid is raised by capillarity. The smaller the area of the upper end of the liquid column, the greater the concavity, and, as a consequence, the greater the strength of the surface film in comparison with the weight of the column raised.

When two glass plates are arranged at a slight angle with reference to each other, with their edges in contact, as

FIG. 47.

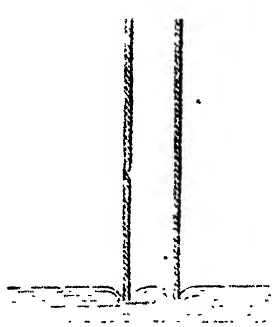
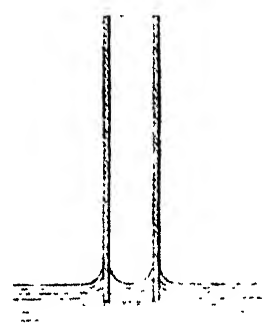


FIG. 48.



shown in Fig. 50, the liquid exhibits the phenomenon shown by the tubes of different diameter, but to a less degree, owing to the contact of the edge of the surface film of the liquid with proportionately a smaller surface. When two glass *plates are presented in a similar manner to the surface* of a liquid which does not wet them, such as mercury or water covered with lycopodium, the effect is the opposite of that just described (Fig. 51). Capillary elevation and depression are more clearly shown by the experiment illustrated in Fig. 52. Two ½ inch glass tubes terminating in capillary tubes are bent into U shape and mounted upon a support. Into the larger end of one of the tubes is poured mercury, which flows into the smaller branch, but does not reach the level of the mercury in the larger branch.

The upper surface of the mercury in each branch of the tube is convex. When water is poured into the larger branch of the other tube, it rises in the capillary tube above its source, and its upper surface in each branch is concave.

FIG. 49.

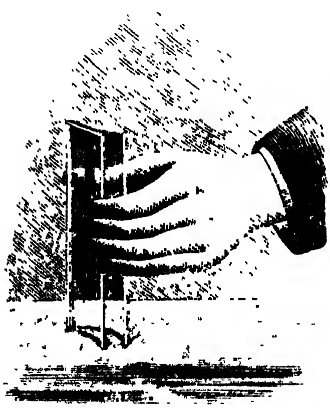
A curious example of the effect of surface tension is shown in Fig. 53. The smaller end of a tapering tube is plunged several times into a vessel of water and withdrawn. Whenever it is drawn out of the water, the contraction of the water drop adhering to the lower end of the tapering tube forces the column higher within the tube, until at length a point is reached when equilibrium is established, the contractile force of the drop being balanced by the weight of the column of water contained by the tube and by the upward pull of the film at the upper surface of the water.

In Figs. 54 and 55 are illustrated experiments showing the force of capillary attraction and adhesion. In Fig. 54 is shown a ¾ inch tube open at one end and terminating in a capillary tubulure at the other end. By allowing the tube to sink for two or three inches in water, with the larger end downward, then placing a minute drop of water in the capillary end of the tube, the tube may be raised two or three inches, carrying with it the column of water contained by it. If the capillary end of the tube be closed by a small drop of water, and the larger end be plunged into water, as in Fig. 55, air will be retained in

FIG. 50

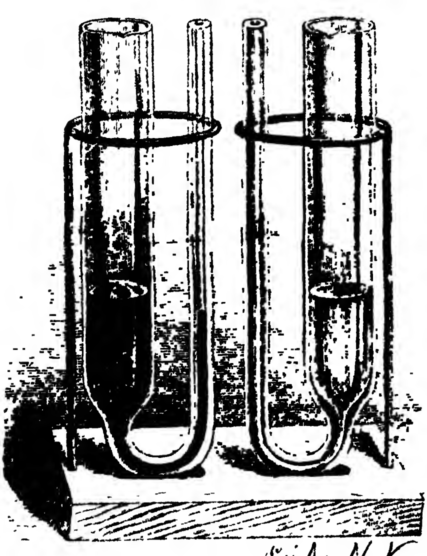
the tube, and, as a consequence, the water cannot enter. An experiment showing a phase of capillarity is illustrated by Fig. 56. This experiment was originally intended for illustrating upon the screen tapestry and other designs formed of small squares, in colors; but it has another practical application, which is capable of considerable expansion. For projection, a piece of brass wire cloth, of any desired mesh, say from 12 to 20 to the inch, is mounted in a metallic frame to adapt it to the slide holder of the lantern, and the wire cloth is coated lightly with lacquer and allowed to dry.

FIG. 51.



The slide thus prepared is placed in the lantern and focused. The required design may now be traced by means of a small camel's hair brush, colored inks or aqueous solutions of aniline dyes being used. The small squares of the wire cloth are filled with the colored liquid, and show as colored squares upon the screen. Different colors may be placed in juxtaposition

FIG. 52.



Capillary Elevation and Depression.

FIG. 53.

Effect of Surface Tension.

without liability to mixing, and a design traced without special care will appear regular, as the rectangular apertures of the wire cloth control the different parts of the design.

FIG. 54.

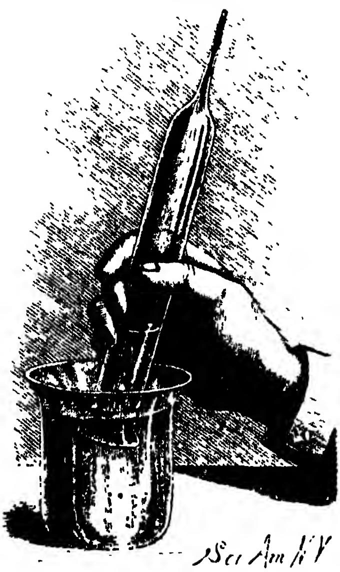
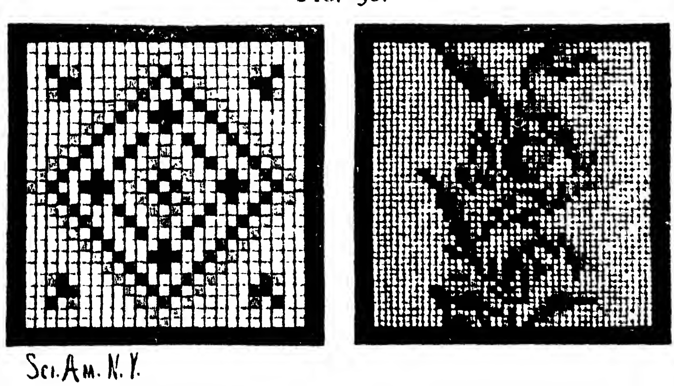


FIG. 55.

The colored liquid squares are retained in the meshes of the wire cloth by capillarity. A damp sponge will remove the color, so that the experiment may be repeated as often

FIG. 56.



Method of Producing Designs on Wire Cloth.

as desired. In this experiment the colored squares have the appearance of gems. These designs may be made permanent by employing solutions of colored gelatine; but in

this case the squares are so small that they are not very effective without magnification. Really elegant designs may be produced in this way for lamp shades, window and fire screens, signs, etc. The mesh of the wire cloth should be quite coarse, say 10 to the inch. The wire cloth is supported a short distance from a design drawn on paper, and the different colors are introduced into the meshes by means of an ordinary writing pen. The gelatine solution should not be very thick, and it must be kept warm. Ordinary transparent gelatine may be colored for this purpose by adding aniline. Colored lacquers answer admirably for filling the squares. The beauty of this kind of work and the simplicity of the method by which it is produced recommend it for many purposes.

ABSORPTION OF GASES.

The behavior of gases under certain conditions is of peculiar interest to the student of physics, since it involves actions which cannot be seen and which require purely mental effort for their comprehension. There are simple ways of demonstrating that certain actions do occur, but the exact mode of their occurrence is left to reason or conjecture.

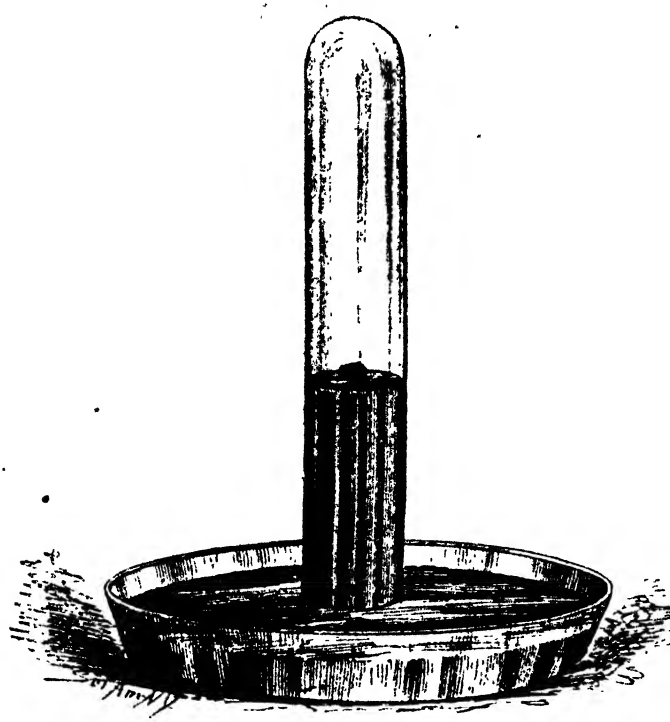
In some of the following experiments molecular action proceeds with astonishing rapidity. One of the best examples of this rapid action is the absorption of gases by char coal.

To illustrate absorption according to the usual method, a piece of recently heated charcoal is floated upon mercury and a test tube filled with carbonic acid gas or ammonia gas is inverted over it and quickly plunged into the mercury, Fig. 57. The absorption begins immediately and quickly forms a partial vacuum, which causes the mercury to rise in the tube.

When a quantity of mercury is not available, the experiment may be performed very satisfactorily in the manner illustrated by Fig. 58. A glass tube, closed at one end by a cork in which is inserted a short piece of smaller tube, is plunged open end downward into a tumbler partly filled with water. To a flask or bottle is fitted a cork in which is

inserted a small glass tube, and the two small tubes are connected by a short piece of flexible rubber tubing. The flask is filled with carbonic acid gas,* and corked. One or two small pieces of fine charcoal are heated strongly in a closed vessel, such as a covered crucible, or upon the top of a stove. The cork of the flask is removed, and the charcoal is dropped

FIG. 57.



Absorption of Gases by Charcoal.

in and the cork replaced. If there are no leaks, the absorption of the gas by the charcoal will be immediately shown by the rise of the water in the tube in the tumbler. The coal will absorb 35 times its bulk of the gas. In the case of ammonia the volume of gas absorbed reaches 90 times the bulk of the charcoal. As the gases which are most easily

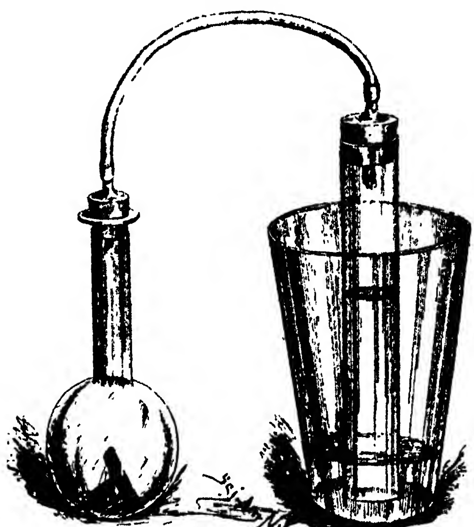
* Carbonic acid gas for this and subsequent experiments may be readily prepared by dissolving a small quantity of carbonate of soda (say 1 oz.) in water, in a tall glass or earthen vessel, then slowly adding a few drops of sulphuric acid. The gas will quickly fill the vessel to overflowing. The carbonic acid gas being much heavier than air, may be readily poured into the flask.

condensed to a liquid state are those which are absorbed with the greatest facility, it is fair to presume that the gases absorbed by the charcoal are in a liquid state. The well known purifying property of charcoal and other porous substances is referred to their absorptive power.

THE DIFFUSION OF GASES.

The tendency of gases to mix or diffuse one into the other is very strong. A simple experiment exemplifying

FIG. 58.



Absorption of Carbonic Acid Gas by Charcoal.

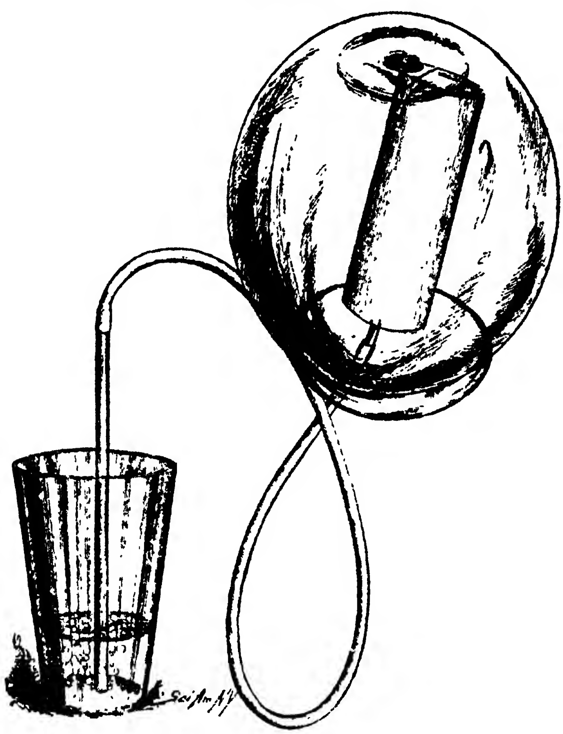
this tendency is illustrated by Figs. 59 and 60. A clean, dry porous cell, such as is used in galvanic batteries, is closed by a cork in which is inserted a small glass tube. A piece of barometer tube six or eight inches long is connected by rubber tubing with the tube of the porous cell. The end of the barometer tube is plunged into water and the porous cell is introduced into a vessel* filled with hydrogen or illuminating gas. The gas enters the porous cell so much more

* An ordinary fish globe answers admirably as a gas-containing vessel for this and similar experiments. It is readily filled with illuminating gas by placing it for a minute in an inverted position over a burner through which gas is flowing.

rapidly than the air can escape through the pores of the cell that a pressure is created which causes the air to escape through the tube and bubble up through the water.

When the porous cell is removed from the glass globe, the reverse of what has been described occurs, the gas passing outward with much greater rapidity than the air can pass in, thereby producing a partial vacuum, which causes

FIG. 59.



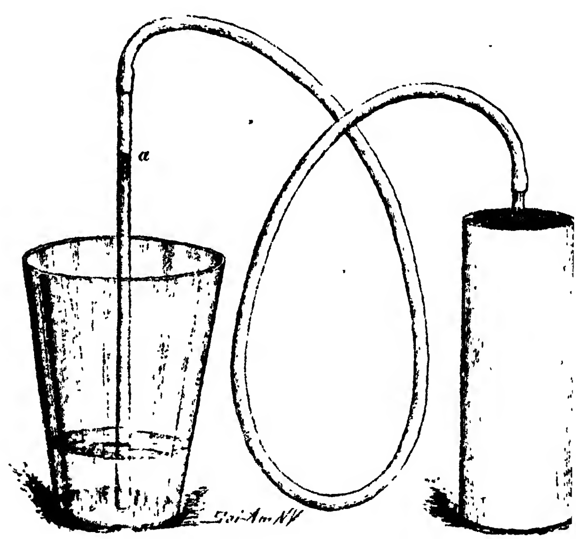
The Diffusion of Gases—Endosmose.

the water to rise to *a* in the glass tube, Fig. 60. These are examples respectively of endosmose and exosmose. In these experiments it is of vital importance to have tight joints, as the slightest leak will insure failure. The corks should fit tightly, and where they are not to be removed, they should be carefully sealed.

These experiments may be tried on a large scale by employing a porous Turkish water cooler instead of the

porous cell, and using a larger and longer glass tube. large bell glass or glass shade may serve as the gas-contai ing vessel. The action may be made more distinctly vi ble by coloring the water.

A convenient and inexpensive way of showing the sam phenomena on a small scale is illustrated by Fig. 61. A ordinary clay tobacco pipe answers for the porous vesse A short, centrally apertured cork is fitted to the bowl (the pipe, a glass tube, of about one-eighth inch intern diameter, is fitted to the bore of the cork, and the cork i carefully sealed. By connecting the stem of the pipe wit

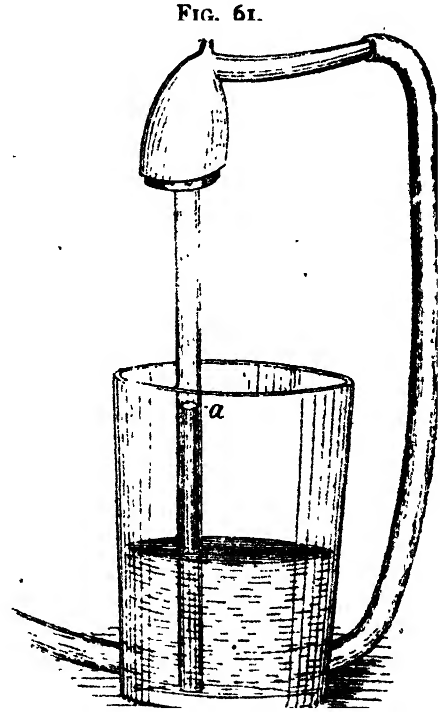


a gas jet or hydrogen generator, by means of a flexible tube, and inserting the glass tube a short distance into water, the gas will bubble up through the water. After shutting off the gas at the burner, or by doubling or pinching the rubber tube, the water will immediately rise in the glass tube—showing that in the exchange of gas and air through the pores of the clay, the outward movement of the gas has been much more rapid than the inward movement of the air, thereby producing a partial vacuum, which causes the water to rise.

By breaking off the stem of the pipe near the bowl, the pipe and glass tube may be plunged in a deep glass jar, when the experiment may be proceeded with as follows:

A little water, say one-half inch in depth, is poured into the jar, after which the jar is filled with carbonic acid gas. Illuminating gas or hydrogen is allowed to flow through the pipe while it is removed from the jar, so as to drive out all the air and fill the pipe with gas. The gas is now shut off and the pipe is immediately placed in the jar, with the glass tube plunged in the water. The effect is the same as in the case of the air and gas, *i. e.*, the carbonic acid gas goes in and the hydrogen gas goes out; and when equilibrium is established, the pipe will contain some carbonic acid. This may be proved by removing the pipe from the jar and plunging the glass tube into some clear lime water, then allowing the gas to flow only long enough to force out the contents of the pipe. The presence of the carbonic acid is indicated by the milky appearance of the lime water, which is due to the formation of carbonate of lime.

Fig. 61.

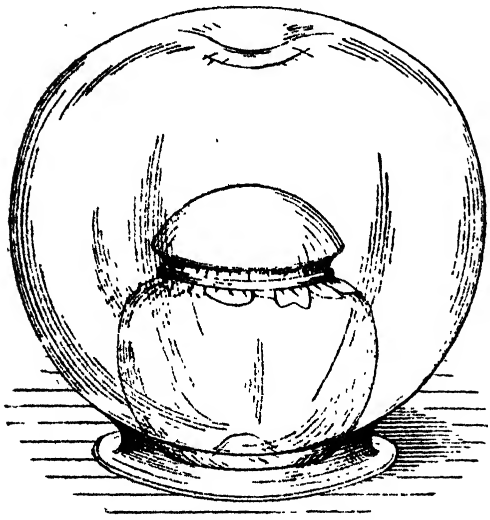


Simple Way of Showing the Diffusion of Gases.

There is sufficient carbonic acid in the exhalations of the lungs to show an action which is the reverse of that observed in connection with illuminating gas. When the pipe is blown through, and the end of the stem is quickly and completely stopped, one or two bubbles will escape from the glass tube, showing that the inward movement of the air through the pores of the clay is more energetic than the outward movement of the carbonic acid.

The diffusion of gases may be shown by the well known experiments illustrated by Figs. 62 and 63. A medium sized fish globe, a very small fish globe which will pass into the larger one, and a piece of bladder are the requisites for this experiment.

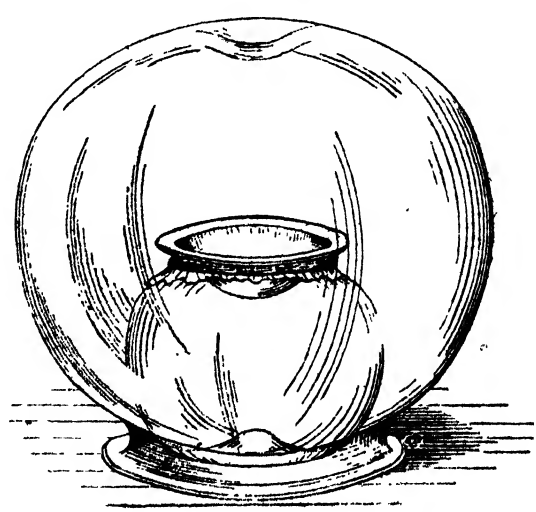
Fig. 62.



Pressure by Endosmose.

The small globe is filled with carbonic acid gas, and the bladder, previously moistened, is placed loosely over the mouth of the jar and tied so as to render the connection between the bladder and the globe air tight. A good way to insure a tight joint is to stretch a wide rubber band around the neck of the globe before applying the membrane. The large fish globe is filled with hydrogen or illuminating gas, and the small globe is placed under it as shown in Fig. 62. As the hydrogen passes inward through the membrane much more rapidly than the carbonic acid passes outward, the membrane is distended outwardly. It requires a little time to produce a visible effect. If the smaller globe is filled with hydrogen, and the large one with

Fig. 63.



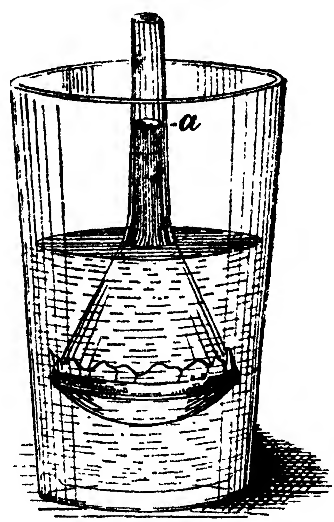
Partial Vacuum by Exosmose.

carbonic acid, the membrane will be distended inward, as shown in Fig. 63. In this latter case the experiment may be performed with the least trouble by placing the large globe with its mouth upward, and closing it by means of a plate of glass.

Endosmose proceeds from the rarer toward the denser gas. The law governing the diffusion of gases, according to Graham, is that *the force of diffusion is inversely as the square roots of the densities of the gases.*

When two miscible liquids are separated by a porous partition, they diffuse one into the other. A simple endosmometer for showing this action is shown in Fig. 64. It consists of a small funnel having its mouth closed by a piece of bladder held in place by a wide rubber band stretched around the rim of the funnel. The funnel thus prepared is immersed in water, for example, and is filled to the level of the water with sirup of sugar. The water passes through the bladder into the funnel and the sirup passes out. The rise of the liquid in the funnel indicates that the water enters more rapidly than the sirup escapes. The presence of the sirup in the water may be detected by taste. That the water passes through the membrane into the funnel may be proved by adding to the water a small quantity of sulphate of iron, and after the experiment has proceeded for a time, adding some tannin to the contents of the funnel. If sulphate of iron is present in the funnel, the sirup will turn dark upon the addition of the tannin.

FIG. 64.



Endosmometer.

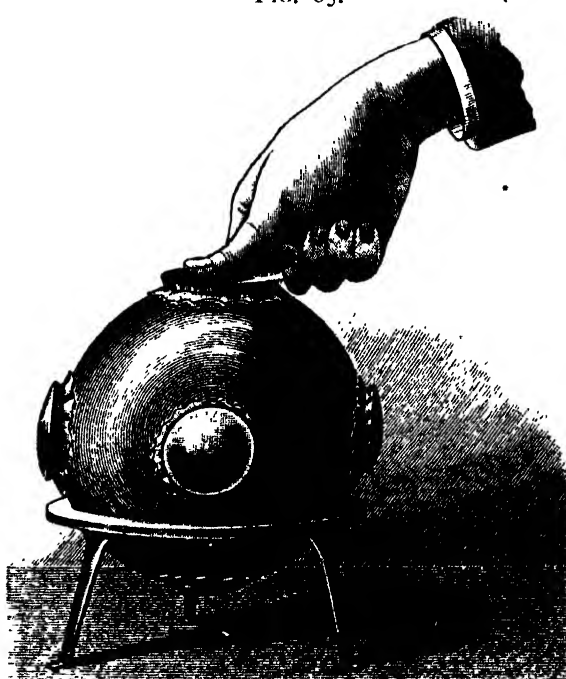
If the neck of the funnel proves to be too short, a glass tube may be connected with it by means of a short piece of rubber tubing.

CHAPTER VI.

LIQUIDS—PRESSURES EXERTED BY LIQUIDS.

Liquids are distinguished from solids by the great mobility of their molecules. The adhesion between the molecules of liquids produces more or less resistance to their free motion. This property, which is known as viscosity, is inherent in all liquids, some exhibiting extreme mobility,

FIG. 65.



Demonstration of Pascal's Law.

others having great viscosity. Ether is an example of a mobile liquid, and an example of a viscous one is found in glycerine.

Liquids are compressible to a very small degree only. They are, as we have already noticed (Chapter I), porous

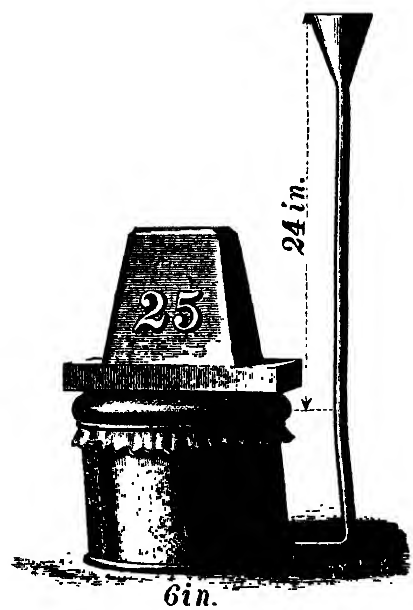
and impenetrable, and, in consequence of their compressibility, they are elastic.

Pascal enunciated the following law of the pressures of liquids: "Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces, and in a direction at right angles to those surfaces."

To demonstrate this principle, the apparatus shown in Fig. 65 has been devised.

A hollow metallic globe is provided with openings at the top and bottom and upon four or more of its sides. Around these openings there are collars, over which are stretched and tied diaphragms of rather thick but elastic rubber, the upper diaphragm being omitted until the globe is filled with water. The globe being placed upon a suitable support, pressure is applied to the upper diaphragm, when it is found that the pressure is transmitted through the medium of the water not only to the diaphragm at the bottom of the globe, but in an equal degree to the diaphragms upon the sides of the globe, thus showing that the pressure is exerted by the water equally in all directions, and at right angles to the surfaces with which it is in contact. This is a simple illustration of Pascal's law.

FIG. 66.

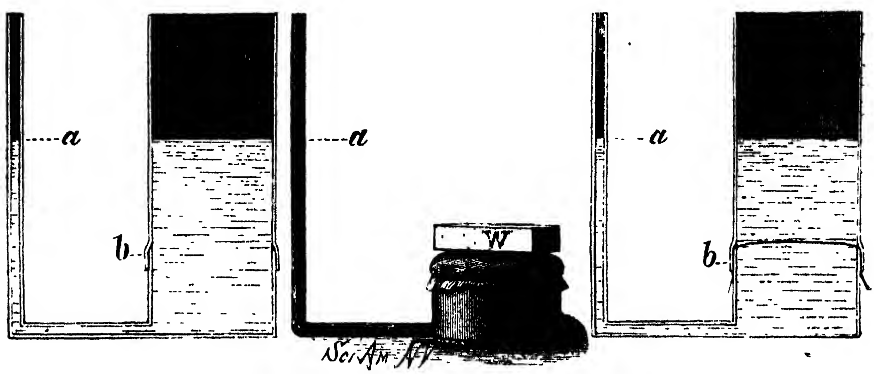


Pascal's Experiment.

Probably there is not a more striking example of the effects of hydrostatic pressure than that presented in Pascal's experiment, in which he burst a stout cask by inserting in it a tube about 30 feet high, and filling both the cask and tube with water. This experiment, in a modified form, is illustrated by Fig. 66. A tin cup of 6 inches diameter, and

having a wired edge, is furnished with a leather or rubber cover, tied over the top of the cup so that it may have a motion of a half inch or more. In the side of the cup is inserted a tube which extends upward above the top of the cup 24 inches, and is furnished at its upper end with a funnel. The diameter of the tube is of no consequence; the result will be the same whether it is small or large. The cup is filled with water by submerging it with the tube in a horizontal position, with the tube uppermost, and alternately pressing in the flexible covering and then drawing it outward. This operation soon drives out the air and fills the cup with water. The cup is placed with the pipe in a ver-

FIG. 67. FIG. 68. FIG. 69.



Equilibrium in Communicating Vessels.

tical position, and a board is laid over the flexible cover and pressed to expel all of the water above the rim of the cup.

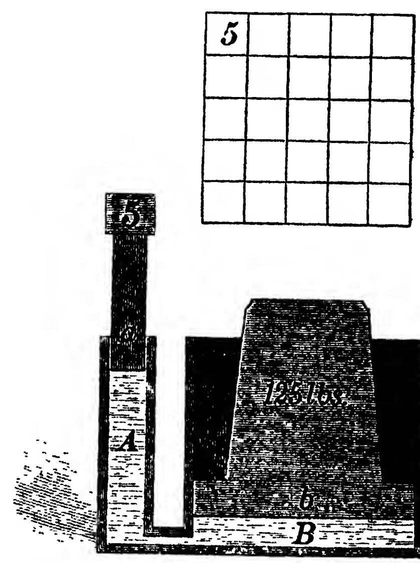
Now, by placing a twenty-five pound weight upon the board and pouring water into the tube, the weight will be lifted and sustained. This experiment shows that a great pressure may be produced by a small column of water. In this case the cup, with its flexible cover, represents the large cylinder and piston of a hydraulic press; the tube stands for the pump cylinder, the small water column in the tube for the piston, and the weight of the column for the power applied. By increasing the height of the water column, the pressure will be correspondingly increased.

Fig. 67 shows two communicating vessels of different diameter. The larger one is divided at a point, *b*, near its

base, and reunited by means of a packed joint. When water is poured into one of these vessels, it rises to the same level in both. By removing the upper portion of the larger vessel and tying a flexible cover over the lower part, it is found that a column of water in the smaller vessel extending to the point, *a*, will be exactly counterbalanced by a certain weight placed on the flexible cover, as in Fig. 68. The weight required will be exactly that of a column of water of the diameter of the larger vessel and equal in height to the distance between the flexible cover and the level of the smaller column, *a*. This may be shown by removing the weight, replacing the upper part of the larger vessel, as in Fig. 69, and filling it with water up to the level, *a*. The weight of water required in the larger vessel to thus lift the smaller column to the point, *a*, will be found to be the same as that of the weight removed.

It seems puzzling that no variation in the size or form of the upper portion of the larger vessel can make any difference in the results, provided the same water level is maintained; but it must be remembered that the whole question is simply one of pressure per square inch. The weight will as readily balance a large column as a small one, the vertical height being the same in each case.

FIG. 70.



Principle of Hydraulic Press.

The enormous pressure developed in a hydraulic press is a subject of wonder, even to those who perfectly understand the principle involved in its operation. Men regard with interest anything that furnishes an exhibition of power, and it is difficult to avoid thinking that in the hydraulic press power is actually created in some mysterious way.

However, nothing of this kind happens. A hydraulic press is simply a power converter, in which a certain pressure per square inch, acting on a small area, is able to produce the same pressure per square inch on a large area, thereby multiplying the pressure. The sum total of all the power utilized in the press is exactly equal to the sum total of all the power applied to the press, less friction.

In Fig. 70 is illustrated a hypothetical hydraulic press, above which is given a diagram showing the relative areas upon which pressure is exerted. To the two communicating vessels, A, B, with square cross sections, are fitted the pistons, *a*, *b*. The piston, *a*, is one inch square, and consequently has an area of one square inch. The piston, *b*, is 5 inches square, and consequently has an area of 25 square inches. If the spaces below the pistons be filled with water, it will be found that, in consequence of the equal distribution of pressure throughout the confined body of water, a weight placed on the piston, *a*, will balance a weight twenty-five times as great placed upon the piston, *b*; that, for example, a downward pressure of five pounds upon the piston, *a*, will, through the medium of the water, cause a pressure of five pounds to be exerted on every square inch of surface touched by the water, and that the movable piston, *b*, having twenty-five times the area of the piston, *a*, and receiving on each square inch of its surface a pressure of five pounds, will be forced upward with a pressure of one hundred and twenty-five pounds.

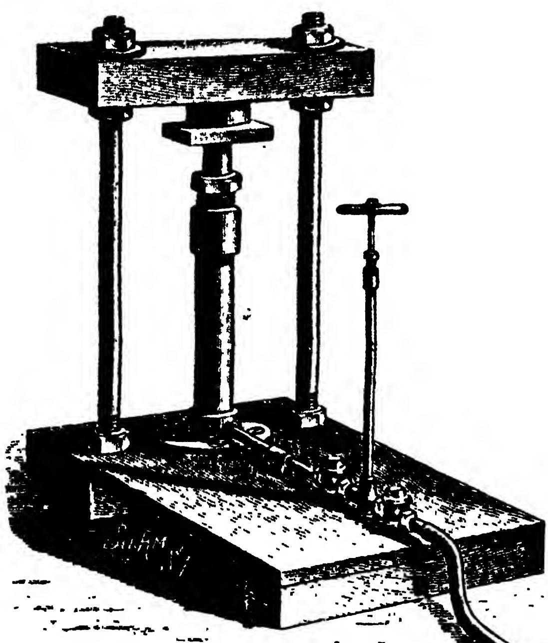
A press of this description would have no practical value, inasmuch as a movement of the piston, *a*, through the space of five inches would lift the piston, *b*, only one-fifth of an inch. To lift the piston, *b*, five inches would necessitate a piston, *a*, having a length of one hundred and twenty-five inches (over ten feet).

To obviate this difficulty, the pump piston of a hydraulic press is of a reasonable length, and valves are provided by means of which the short piston, by acting repeatedly, will accomplish the same results as would in the other case require a very long piston.

In Figs. 71 and 72 is shown a very simple and easily constructed hydraulic press, which has considerable utility. It is made of pipe fittings, valves, rods and bolts, that are all procurable almost anywhere.

To the baseboard is secured a flange, into which is screwed a short piece, A, of gas pipe. On the upper end of the pipe is screwed a coupling, into which is inserted a bushing from which the internal thread has been removed. In the bushing and in the pipe, A, is inserted a rod of cold rolled iron,

Fig. 71.



Simple Hydraulic Press.

a bar of brass, or a short section of shafting, and the space in the coupling around the rod is filled with hemp packing, which may be compressed, if required from time to time, by screwing in the bushing. The flange at the bottom of the pipe, A, is connected with the pump, B, by the pipe, C, in which is inserted a discharge, as shown. The pump cylinder is inserted in a crosstee, to opposite sides of which are attached ordinary check valves. The tee is fastened to the base by a plugged piece of pipe, extending through the

base and provided with a nut, which clamps the base tightly. The barrel of the pump is in all respects like the press barrel, except in size. The piston consists of a ¼ inch brass rod, to the upper end of which is attached a tee handle.

A heavy bar of wood is supported over the pipe, A, by bolts extending through the base and through a re-enforc-

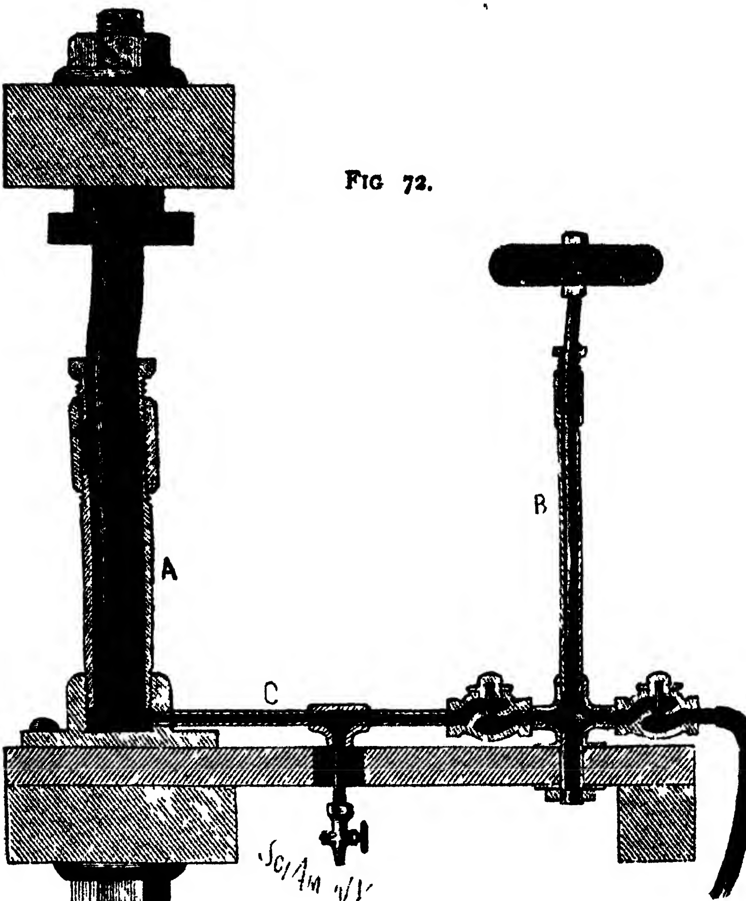


FIG 72.

Sectional View of Simple Hydraulic Press.

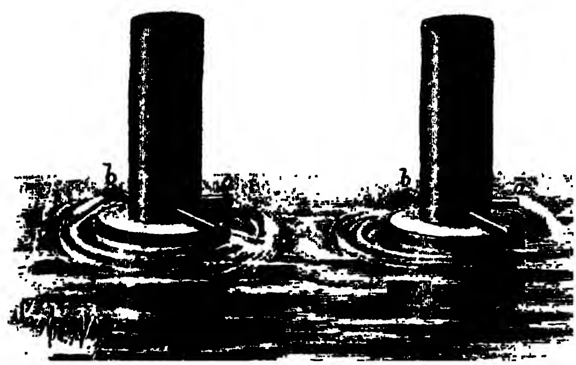
ing bar under the base. The check valves both open toward the cylinder, A, and the outer one is provided with a rubber suction pipe. Water is drawn into the pump by lifting the piston and forced into the press barrel by the descent of the piston. The proportion of the pressure attained, to the power applied, will be as the area of the large

piston to the area of the small one. With pistons of respectively 2 inches and ¼ inch diameter, a pressure of 3,000 pounds may be produced easily. If it is desired to create a greater pressure, the barrel, A, may be made of hydraulic tubing, and a lever may be applied to the pump piston, or the diameter of the barrel, A, and its piston may be increased.

LATERAL PRESSURES.

In some experiments already described it was shown that hydrostatic pressure is equally distributed on all sides of the containing vessel. Fig. 73 illustrates an experiment

Fig. 73.



Reactionary Apparatus

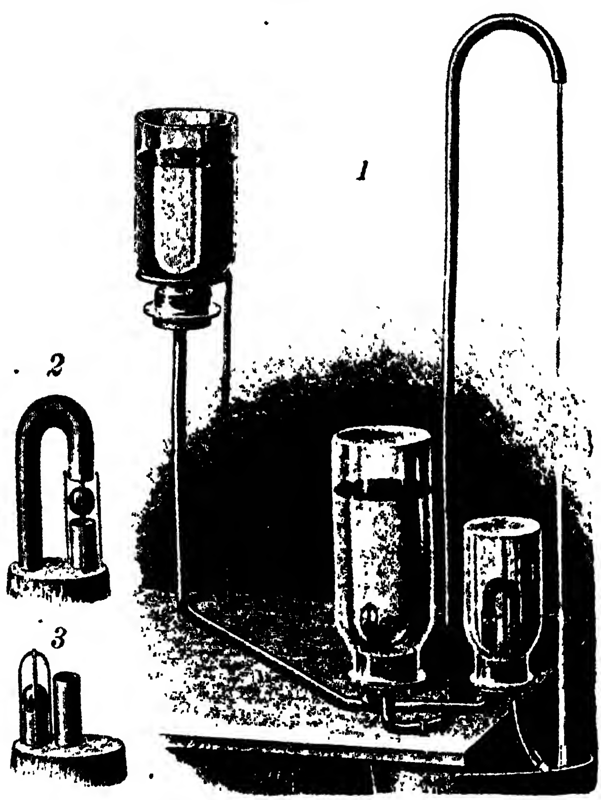
in which are shown the effects of removing pressure from a portion of one side of the vessel, thus allowing the pressure to act upon the opposite side of the vessel in such a manner as to cause it to move. This experiment is arranged to show this action in two ways, one so as to propel the vessel forward, the other so as to cause it to turn.

The apparatus consists of a tall tin can—such as is used by fancy bakers for wafers or fine crackers—mounted upon a wooden float provided with a lead ballast to keep it in an upright position. In one side of the can at the bottom is inserted a short tube, *a*, and in diametrically opposite sides of the can, also at the bottom, are inserted longer tubes, *b*, which reach over the wooden block and have their ends

turned in opposite directions. All of the tubes are stopped, and the float is placed in a large vessel of water, when the can is filled with water and the stopper of the tube, *a*, is withdrawn, thereby allowing water to escape from the can, and by reaction drive the can backward.

When the straight tube, *a*, remains closed, and the bent tubes, *b*, are opened, the reaction of the issuing streams results in the rotary movement of the apparatus. The

FIG. 74.



Hydraulic Ram.

apparatus arranged in this way illustrates the principle of Barker's mill.

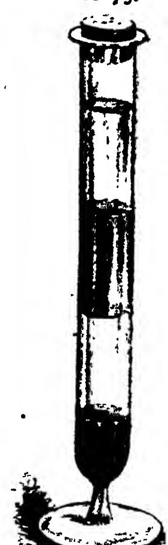
The hydraulic ram, a simple form of which is illustrated in Fig. 74, depends for its action on the momentum of the water column and upon the elasticity of air. The reservoir in the present case consists of an inverted glass bottle having no bottom, and provided with a perforated stopper in

which is inserted one end of a tube, preferably lead, on account of the facility with which it may be cut and bent. The other end of the tube is branched, one branch extending through a stopper inserted in an inverted bottle which serves as an air chamber. The other branch of the tube extends to the overflow valve. In the stopper of the air chamber is inserted a second tube, which is bent upward and curved over, forming the riser.

The smaller bottle, which serves as a valve chamber, is provided with a stopper which receives the branch of the supply tube and an overflow tube. The arrangement of these tubes is shown in detail at 2, the curved tube being the overflow, the straight one the inlet. To the inlet and overflow tubes is fitted a valve consisting of a metal ball or a marble. The fitting is accomplished by simply driving the ball against the end of each tube, so as to form valve seats. Four wires are inserted in the stopper around the inlet tube to prevent the escape of the valve. The distance which should separate these tubes, as well as the weight of the ball valve, is determined by experiment.

In the air chamber above the branch of the supply tube is confined a ball valve by a cage formed of wires inserted in the stopper, as shown at 3. This valve is fitted in the manner already described.

Fig. 75.



Vial of Four Liquids.

The discharge tube extends above the level of the reservoir. The reservoir and the tubes are supported by wire loops and standards inserted in a base board.

Water flows from the reservoir through the valve chamber and out at the overflow. When the velocity of the flow is sufficient to carry the valve in the valve chamber up against the end of the curved overflow tube, the overflow is immediately checked, and the momentum acquired by the water causes it to continue to flow for an instant into the air chamber, compressing the air in the chamber, and causing the water to rise in the discharge tube. As soon

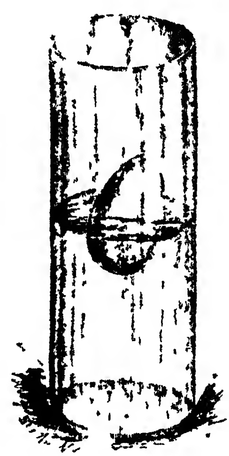
equilibrium is established, the valve in the air chamber closes and the valve in the valve chamber falls away from its seat on the overflow tube, allowing the water to discharge again, and so on, this intermittent action continuing so long as there is water in the reservoir. The water discharged by the riser is only a fraction of that flowing out of the reservoir.

We have already noticed (Fig. 66) that a liquid will assume the same level in communicating vessels. The size and form of the vessels is immaterial. The smaller one may be inclined, curved, or bent in any form and the larger one may have any capacity, still the result will be the same.

FIG 76.

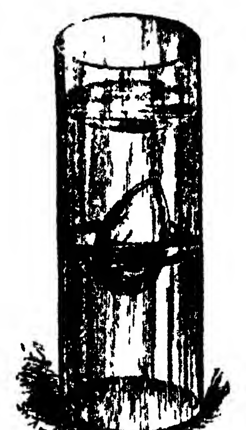
Egg in Fresh Water.

FIG 77.



Egg Buoyed up by Salt Water.

FIG. 78.



Egg in Equilibrium between two Liquids of Different Densities.

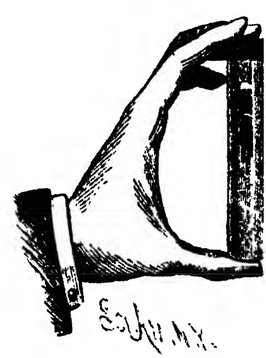
When, however, the vessels contain liquids of different densities, the level will be no longer the same. In such case the lighter liquid will stand higher.

When several liquids of different densities which do not mix are contained in the same vessel, there will be stable equilibrium only when the liquids are arranged in the order of their densities, the heavier liquid being, of course, at the bottom. This is illustrated by the "vial of four liquids," shown in Fig. 75. A test tube with a foot makes a convenient receptacle for the liquids. In the bottom of the tube is

placed mercury. The second liquid in order is a solution of carbonate of potash in water. The third is alco-hol, colored with a little aniline red to mark the division of the liquids more clearly. The fourth is kerosene oil. When these liquids are shaken up, they mix mechanically but when the tube is at rest the liquids quickly arrange themselves in their original order.

The experiment illustrated in Figs. 76, 77, and 78 shows the effects of liquids of different densities. Two pint tumblers or similar vessels are necessary for this experiment. Half fill one with water and the other with strong brine. Into the water drop an egg. It goes to the bottom (Fig. 76). An egg dropped into the brine floats (Fig. 77). By carefully pouring the brine through a long funnel or through a funnel with an attached tube, which will reach to the bottom of the tumbler containing the pure water, the water and the egg will be lifted, and the egg will float in equilibrium at the middle of the tumbler.

FIG. 79.



The Cartesian Diver.

The first experiment shows that the egg is a little more dense than pure water, the second that brine is more dense than the egg, and the third that the egg can be supported in equilibrium between two liquids of different densities.

The hydrostatic toy known as the Cartesian diver illustrates the several conditions of floating, immersion, and suspension in equilibrium. In a tall, slim glass tube, closed at the bottom and filled with water, is placed a porcelain or glass figure having a glass bulb attached to its head. The glass bulb has a small hole in the bottom, and is filled partly with water and partly with air, the proportion of air and water being such as to just allow the bulb to float. The top of the tube is closed by a piece of flexible rubber tied over its mouth. The pressure of the fingers upon the rubber communicates pressure through the water to the air

contained by the bulb, causing the air to occupy less space and increasing the weight of the bulb in proportion to the amount of water forced in. As the weight of the bulb increases the diver descends, and when the finger is removed from the elastic cover of the tube, the air by its own elasticity regains its normal volume, and the bulb, becoming lighter, rises to the top of the jar.

CHAPTER VII.

GASES.

Gases are elastic fluids in which the molecular force of repulsion is superior to the force of attraction. Expansion, the most characteristic property of gases, is due to this force. The limit of the expansive force of a gas is unknown. If there were no opposing causes, it would appear that the particles of a gas might separate indefinitely.

The expansive force of the atmosphere is opposed by the earth's attraction; the air is thus in a state of equilibrium.

FIG. 80.

Dilatation of Balloon in a Vacuum.

The expansibility of air is shown by inclosing a small quantity of it at atmospheric pressure in an elastic rubber balloon,* and placing the balloon in the receiver of an air pump, then removing the atmospheric pressure from the exterior of the balloon by exhausting the receiver. The air in the balloon will expand, distending it as shown in Fig. 80.

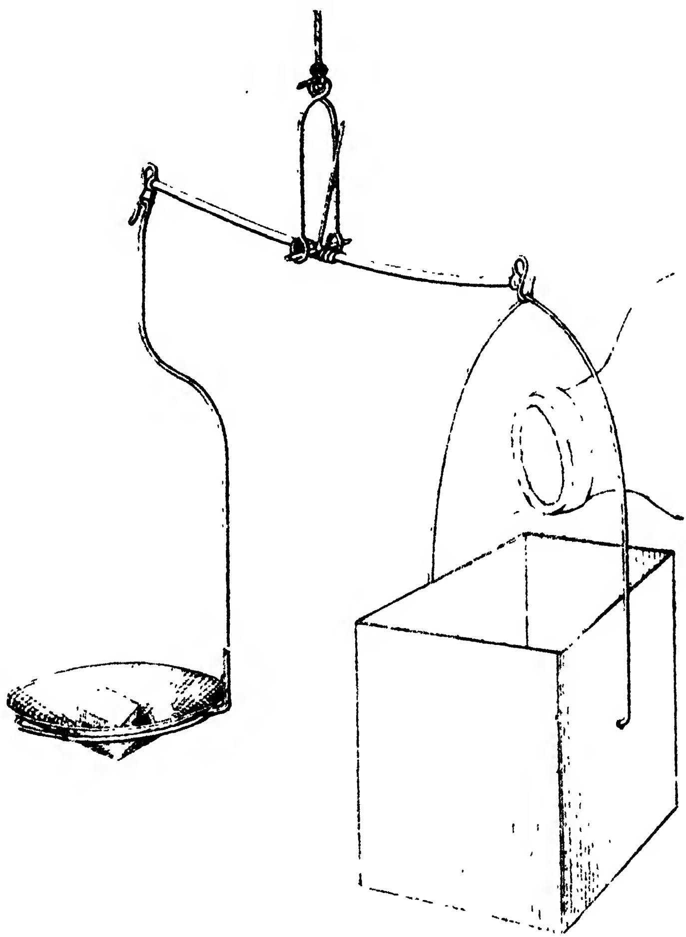
In former experiments illustrating the diffusion of gases, it was shown that carbonic acid gas was very much heavier than air, by pouring the gas from one vessel to another, thus to a great extent displacing the air in the receiving vessel, in the same manner as it would be displaced by the pouring in of a liquid. In the case of pure hydrogen or illuminating gas, the order

* The small inflatable balloons applied to the toy squawkers, and which may be bought in any toy store for three cents, answer perfectly for this experiment.

of things was reversed; *i. e.*, to fill the vessel it was necessary to invert it, so that the air might be displaced by the rising of the gas, which is so much lighter than air.

To show visibly that one gas is heavier than air and the other lighter, a pair of balances may be pressed into service. If the balances are not at hand, a pair may readily

FIG. 81.



Weighing Gases.

be made of wire, as shown in the engraving. All the pivots should be made V-shaped, to reduce the friction to a minimum. The pivot of the beam should be a little higher than the bearing surface of the hooks at the ends of the beam. The conical scale pan may be made of paper, by radially slitting a disk, overlapping the edges, and sticking them to-

gether. The paper box for receiving the gas is five inches in each of its dimensions, and is suspended from the scale beam by a wire stirrup, so that it may be reversed. After bringing the scale to equilibrium in air by placing some small weights in the pan, the air contained by the box may be displaced by pouring in carbonic acid gas. The box will immediately descend, showing that carbonic acid gas is

FIG. 82.

Gas Wheel.

heavier than air. Allowing the weights in the pan to remain the same, the paper box is inverted, when the carbonic acid falls out, and air takes its place. The balance beam again becomes horizontal. Now, by opening a jar of hydrogen under the box, the air is again displaced, this time, however, by the rising of the inflowing gas. When the greater portion of the air is replaced by hydrogen, the box rises, show-

ing by its buoyancy that its contents are lighter than air. If the balance is allowed to remain for a time, the gas will be diffused, and the balance beam will return again to the horizontal position.

To determine the weight of air, a globe provided with a stop cock is completely exhausted and weighed. Air is then admitted and the globe is again weighed, when its weight will be greater than before. The difference between the

Fig. 83.

Hand Glass.

weight in the first and second cases will be the weight of the air contained by the globe.

One hundred cubic inches of dry air under an atmospheric pressure of 30 inches, and at the temperature of 60° Fahrenheit, weigh 31 grains. The same volume of carbonic acid under the same conditions weighs 47·23 grains, 100 cubic inches of hydrogen weigh 2·14 grains.

Air at the same pressure and at a temperature of 32° is about $\frac{1}{773}$ as heavy as water.

In Fig. 82 is shown a very simple wheel, to be operated by gases. The wheel consists of a disk of light but stiff card board, mounted between two corks on a straight knitting needle, and provided around its periphery with buckets formed of squares of writing paper, attached to the periphery of the disk by two adjoining edges so as to form hollow cones, as shown. The knitting needle is journaled in wire or wooden standards, and lubricated so that it may turn freely. Carbonic acid gas may be generated in a

Fig. 84.

Rubber Forced Inward by Air Pressure

Fig. 85.

Crushing Force of the Atmosphere.

pitcher and poured upon the wheel in the manner illustrated. By making the wheel large enough and carefully balancing it, it may be turned by liberating hydrogen gas under the mouths of the buckets.

To exhibit some of the effects of atmospheric pressure, all that is required besides an air pump, or aspirator, is a large and heavy lamp chimney.

The lamp chimney needs no other preparation for use than the insertion of a five-sixteenths inch tube in the

center of the cork and the thorough sealing of the cork with its tube in the smaller end of the chimney.

A very striking and instructive experiment consists in exhausting the air from the chimney by applying the suction tube of the pump to the tube at the closed end of the chimney, while the palm of the hand is applied to the large open

FIG. 86

Weight Lifted by Air Pressure.

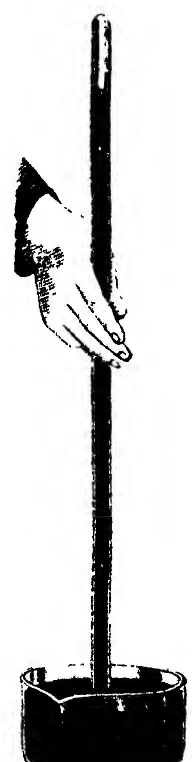
end of the chimney. As the air is exhausted from beneath the hand, the pressure of the atmosphere exerted on the hand drives the palm down into the chimney, as shown in Fig. 83, and as the exhaustion proceeds, the pressure becomes painful and difficult to endure.

It is easy under such circumstances to realize that the

atmosphere has a very appreciable weight. The same fact may be illustrated by tying over the open end of the chimney a thin piece of elastic rubber, then exhausting the air from the chimney, allowing the external air to press the rubber down into the chimney, as shown in Fig. 84.

The disruptive power of atmospheric pressure is illustrated by the rupturing of a thin piece of bladder tied over the open end of the chimney, as shown in Fig. 85. When the air is exhausted from the chimney, the bladder, if thin enough, will burst with a loud report. If the bladder will not readily burst, the rupture may be started by puncturing it with the point of a knife.

FIG. 87.



Mercurial Column Supported by Atmospheric Pressure.

In Fig. 86 is illustrated a similar experiment, in which the inwardly pressed diaphragm is made to raise a weight. A piece of rubber cloth is tied over the open end of the chimney, and a hook is fastened to its center by sewing. The cloth is heavily coated with rubber cement around the sewing of the hook. A weight is placed on the hook, and the air is exhausted as before. The upward pressure of the atmosphere raises the weight. This experiment illustrates the action of a form of vacuum brake now extensively in use; the weight representing the brake.

THE BAROMETER.

The pressure of the atmosphere is plainly exhibited in the mercurial barometer, the simplest form of which is shown in Fig. 87. It consists of a glass tube about 36 inches in length, closed at one end and completely filled with mercury, the open end being plunged into a vessel of mercury. The column will stand at a height of about 30 inches above the level of the mercury in the vessel, showing that the pressure of the atmosphere under ordinary circumstances is equal to that of a column of mercury of about the height

given. The weight of water being to that of mercury as 1 to 13·59, the height of a water column supported by the atmosphere would be about 34 feet.

The original mercurial column experiment of Torricelli was followed by an experiment by Pascal which proved conclusively that the support of the mercurial column was due to atmospheric pressure. It consisted in making simultaneous observations of two barometers, one situated at a high altitude, the other at a lower level. It was thus shown by the descent of the mercurial column, at a high elevation, that atmospheric pressure diminishes in proportion to the ascent.

AN INEXPENSIVE AIR PUMP.

The engraving illustrates an efficient air pump for both exhaustion and compression, which may be made from materials costing one dollar and fifty cents, and with the expenditure of not more than two or three hours' labor.

With this pump, the entire range of ordinary vacuum and plenum experiments may readily be performed by the aid of a few well known and inexpensive articles, such as lamp chimneys, fish globes, a tumbler or so, and pieces of sheet rubber, bladder, etc.

Fig. 88 illustrates the manner of using the pump. Figs. 89 to 92 inclusive are sectional views of the pump and its valves. Fig. 93 shows a form of valve for the compression pump, and Fig. 94 shows the application of a foot pedal to the pump. The materials required are as follows: A piece of so-called pure rubber tubing 1¾ inches external diameter, 1 inch internal diameter, and 9 inches long; a piece of pure rubber tubing 1 inch external diameter, ⅝ inch internal diameter, and 5 inches long; a piece of heavy pure rubber tubing ⅝ inch external diameter and 4 feet long; two wooden valve castings (shown in Fig. 90); a strip of the best oiled silk, ⅜ inch wide and 8 or 10 inches long; and some stout thread.

The piece of one inch rubber tube is cut diagonally at an angle of about 30°, so as to divide it into two similar pieces. The wooden valve casing is pierced longitudinally with a

one-sixteenth inch hole and transversely with a hole ½ inch square, and thoroughly shellacked or soaked in melted paraffine to render it impervious to air. The longitudinal hole is cleared out, and the walls of the square transverse hole are smoothed. One of the walls of the square hole into

FIG. 58

Testing Simple Air Pump.

which the one-sixteenth hole enters forms one valve seat, and the other forms the other valve seat. The valves each consist of two thicknesses of the oiled silk strip stretched loosely over the valve seat, and secured by the thread wound around the wooden valve casing. It will, of course,

be understood that when the valve casings are placed in the 1 inch rubber tubing, and the 1 inch tubes are placed in the ends of the larger tube, as shown in Fig. 89, the valves must both be capable of opening in the same direction, so

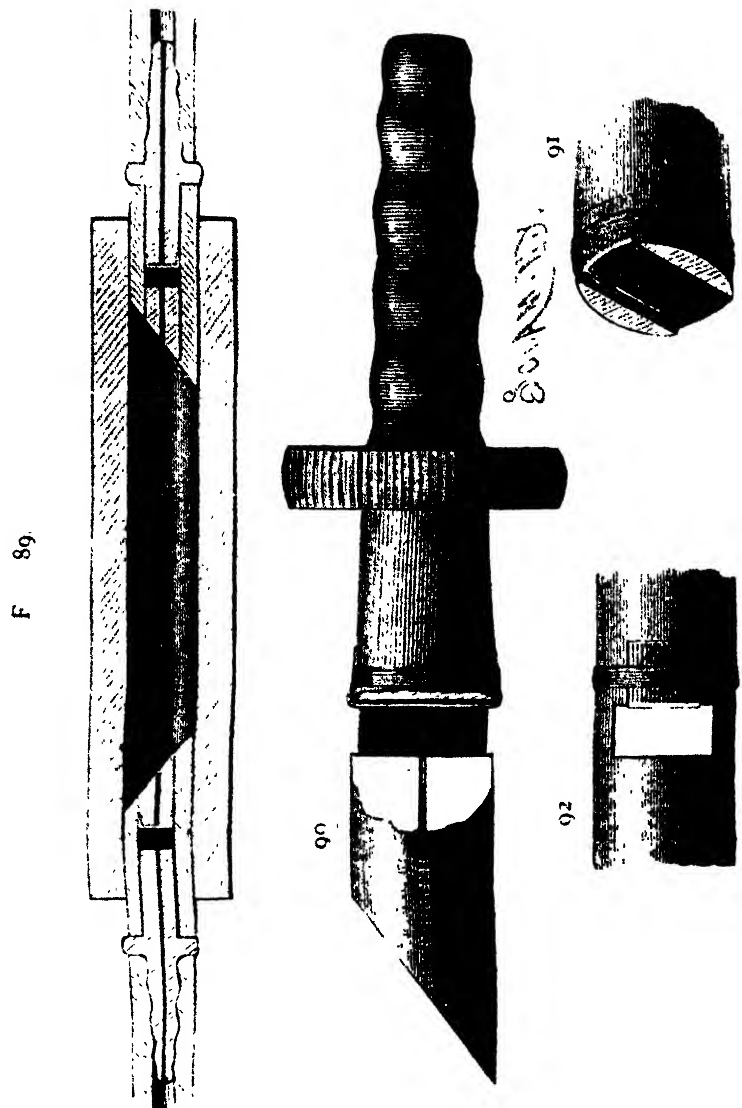


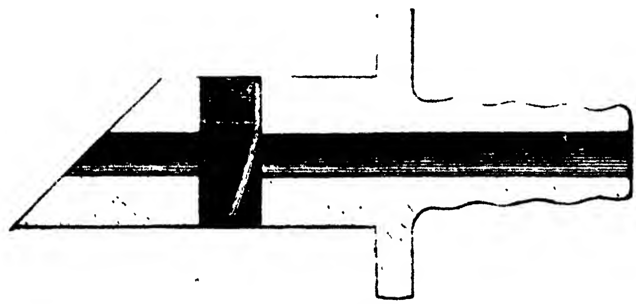
Fig. 89.—Longitudinal Section of Simple Air Pump. Fig. 90.—Valve Casing Partly in Section. Fig. 91.—Transverse Section showing Valve in Perspective. Fig. 92.—Plan View of V[illegible]

that the air may pass through the pump as indicated by the arrow, entering by one valve and escaping by the other.

The pieces of rubber tube inclose the valve casings, so that each valve has a little air-tight chamber of its own to

work in. The beveled ends of the rubber tube are arranged as shown in the engraving, and the inner ends of the wooden valve casings are beveled to correspond, so that when the large rubber tube is placed on the floor and

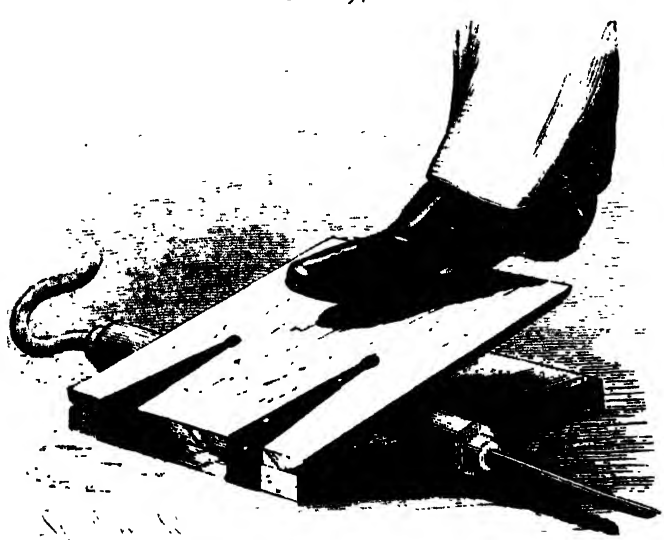
FIG. 93.



Valve for Compression Pump.

pressed by the foot, there will be very little air space left in the pump. The four-foot rubber tube is attached to one end of the pump for vacuum experiments, and to the opposite end for plenum experiments. To avoid any possibility

FIG. 94.



Treadle for Air Pump.

of the sticking of the valves, the valve seats are rubbed over with a very soft lead pencil, thus imparting to them a slight coating of plumbago, to which the oiled silk will not

adhere. As an elastic rubber pump barrel of the kind described requires considerable pressure of the foot to insure the successful operation of the pump, it is advisable to construct a treadle like that shown in Fig. 94. It consists of two short boards hinged together, the lower one having a shallow groove for the reception of the middle part of the pump. The edges of the upper board are beveled at about the same angle as the ends of 1¼ inch rubber tube. The width of the hinged boards should be somewhat less than the length of the chamber in the pump. A mark is made on the side of the larger tube at one end to indicate the top, the proper position for the pump being that shown in Fig. 88.

The pressure of the foot on the side of the pump barrel expels the air through the discharge valve, and when the barrel is released, its own elasticity causes it to expand, and while regaining its normal shape it draws the air from any vessel communicating with the suction valve.

A vacuum sufficient for most of the ordinary experimental work may be produced by means of this pump in a short time. A gauge may be improvised by attaching the suction pipe to a piece of barometer tube about 30 inches long, and dipping the end of the tube in mercury, using a yard measure as a scale, as shown in Fig. 88. The pump will be found to compare favorably with piston pumps.

When it is desired to construct a pump of this kind for compressing air or for a low vacuum, the elastic tube forming the pump barrel may be larger and thinner, and the hole through the wooden valve casing may be made larger, as shown in Fig. 93, and the oiled silk valve may be replaced by a simple rubber flap valve, held in place by a single tack.

The fish globe forms the receiver of the air pump. It is closed by the soft rubber disk, which is supported by the wooden disk, the rubber being secured to the wood by four common screws passing through the rubber into the wood, about midway between the center and circumference of the rubber. Both the board and the rubber are apertured to receive a five-sixteenths brass tube, provided with a fixed collar at the top of the wood, and with a screw collar at the

inner end which is turned down upon the rubber, clamping it to the wood, and at the same time making an air-tight joint around the tube.

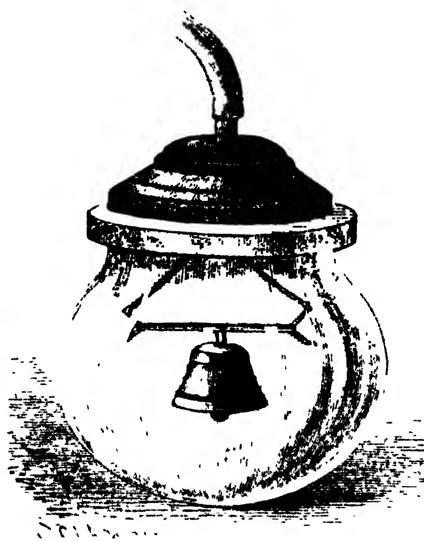
The suction tube of the pump is applied to the small brass tube, and the soft rubber disk is pressed down upon the mouth of the globe, when the operation of producing a vacuum is begun. After a few strokes of the pump, the cover will be retained on the globe by atmospheric pressure, and will need no further holding by the hand.

A great deal of experimental and practical work may be

Fig. 95

Water Boiling in Vacuo.

Fig. 96



Bell in Vacuo.

done with the simple air pump described in the foregoing pages. The apparatus required for the vacuum experiments costs less than the pump. It consists of a fish globe 6 in. in diameter, a disk of thick, soft rubber large enough to cover the fish globe, a plain disk of wood as large as the rubber, two 3 in. pieces of five-sixteenths inch brass tubing, a lamp chimney with a flange on the lower end, a cork fitting the small end of the chimney, a thin piece of bladder, a thin piece of very elastic rubber, a small bell, a tumbler, a small rubber balloon, some sealing wax, some stout thread, and a piece of small wire.

The fact that water boils at a temperature below 212° when the atmospheric pressure is removed, is exhibited by placing a tumbler of hot, but not boiling, water in the receiver, as shown in Fig. 95, then exhausting the air from the receiver.

The bell suspended in the receiver by a light elastic rubber band stretched across a wire fork, whose shank is inserted in the tube of the receiver cover, as shown in Fig. 96, may be distinctly heard when rung in the receiver before exhaustion, but after exhausting the receiver, the bell will be heard feebly, if at all, thus showing that the air when rarefied is a poor sound conductor.

Fig. 97.

Destruction of Life by Removal of Air.

The inability of rarefied air to support life is shown by the experiment illustrated by Fig. 97. A mouse in the receiver soon dies when the air is exhausted.

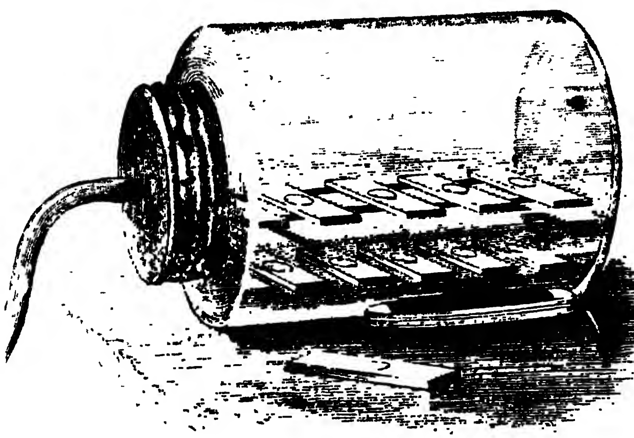
A device for use in connection with the simple air pump for desiccating and for removing air from microscope mounts is shown in Fig. 98. It consists of an ordinary fruit jar having soldered in its cover a short tube, which is adapted to receive the suction tube of the air pump. The objects to be treated are placed in the jar, the cover put on and made tight, and the suction pipe of the pump is applied.

These are mostly well-known vacuum experiments, adapted to the simplified apparatus. There are, of course, many others that may be performed with equal facility by means of this air pump.

With the pump arranged for compression, a large number of experiments of a different character may be performed. A reservoir will be needed, like that shown in Fig. 99. It

consists of a piece of ordinary leader, such as may be procured from any tinman. It should be 3 or 4 in. in diameter and 3 or 4 feet long. Heads are soldered on the ends, and all the seams are made air tight by soldering. A five-sixteenths inch tube is inserted in one end, and another in the

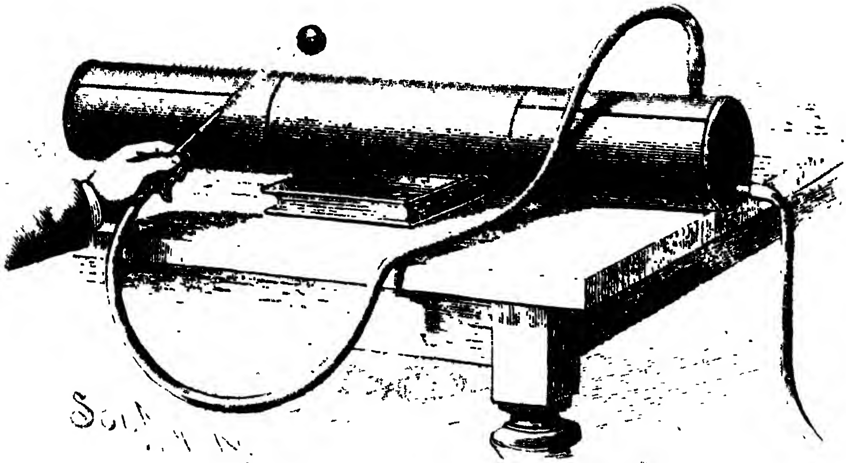
FIG. 98.



Withdrawing Air from Microscope Slides.

side. The discharge end of the pump is connected with one of the tubes of the reservoir, and a rubber tube, having at one end a one-sixteenth inch nozzle of metal or glass, is connected with the other tube of the reservoir. The air

FIG. 99.

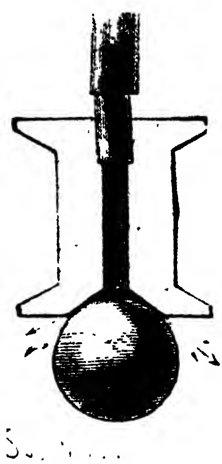


Compressed Air Reservoir and Ball Experiment.

may be confined in the reservoir by doubling the discharge tube or applying to it an ordinary pinch cock. A light ball of cork may be supported in the air jet while the nozzle is held in an inclined position, as shown in Fig. 99.

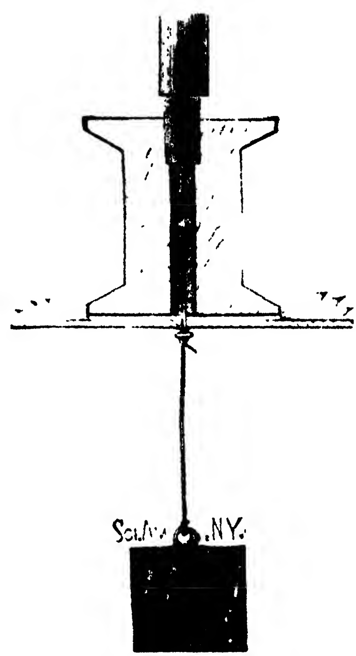
By connecting the discharge pipe of the reservoir with a spool, in the manner shown in Fig. 100, the familiar experiment of sustaining a card, together with an attached weight, by blowing down on the card may be performed.

FIG. 101.



Ball Experiment.

FIG. 100.



Card Experiment.

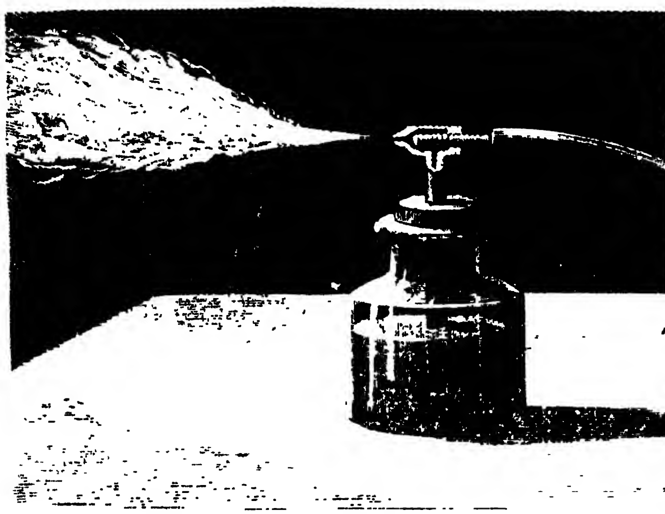
A pin passing through the card into the central aperture of the spool prevents the card from slipping.

Fig. 101 shows a simple way of exhibiting the ball experiment. The ball is held in the concavity of the spool by blowing forcibly outward against it.

In these cases the air issues in a thin sheet, which adheres to and carries away the air adjoining the upper surface of the object supported, thereby producing a partial vacuum into which the object is forced by atmospheric pressure.

In Fig. 102 is shown an atomizer which may be used in connection with the reservoir and air compressor for atomizing liquids for various purposes. In the present case it is represented as an atomizing petroleum burner. A burner of this kind yields a very intense heat, and produces a flame 2 or 3 ft. long. The oil in the vertical tube adheres to the air forced through the horizontal tube and is carried

FIG 102



Atomizing Petroleum Burner.

forward with the air in the form of fine spray, which readily burns as it is ejected from the nozzle. The vacuum formed in the vertical tube is supplied by oil forced up by atmospheric pressure.

ASPIRATORS FOR LABORATORY USE.

Wherever a head of water of ten feet or more is available, an aspirator is by far the most convenient instrument for producing a vacuum for filtration and fractional distillation. It is also adapted to a wide range of physical experiments.

Besides the advantage of convenience and compactness, the aspirator has the further advantage over piston air pumps in the matter of cost. It may be had at prices varying from $1.50 to $4 or $5.

Two kinds are in general use—one of glass, known as Bunsen's filter pump, and shown in Figs. 103 and 104; the other of brass, shown in Figs. 105, 106, and 107.

The glass aspirator can be purchased of almost any dealer in druggists' sundries or chemical glassware. Any expert glass blower can make it in a short time.

This instrument consists of an elongated bulb terminating in a crooked tube at the bottom and having a tapering nozzle

FIG. 103

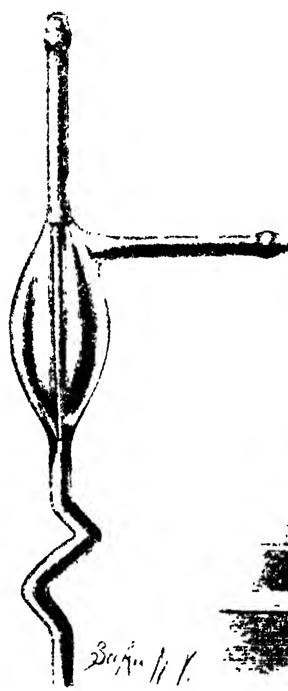
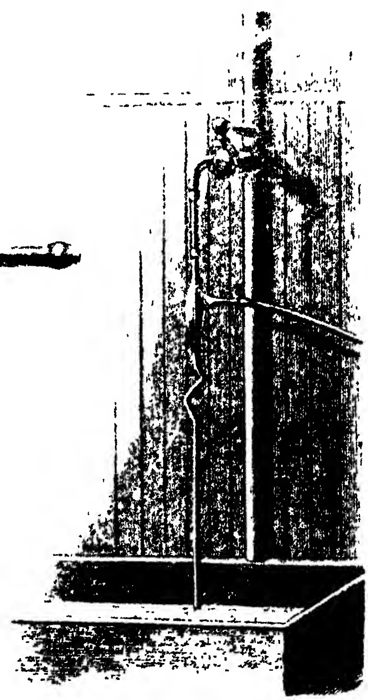


FIG. 104.



Bunsen Filter Pump

inserted in the top and welded. The lower end of the nozzle is located directly opposite and near the crooked discharge tube. A side tube is connected with the bulb at a point near the junction of the nozzle and bulb.

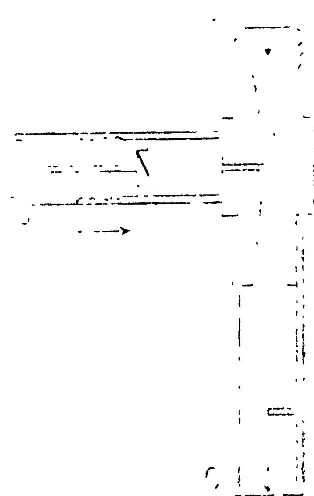
This aspirator is used in the manner indicated in Fig. 104, *i. e.*, the upward extension of the nozzle is connected with a tap by a short piece of rubber tubing, and the side tube is connected by a piece of rubber tubing with the vessel to be exhausted. When the water is allowed to flow through the

aspirator, it leaps across the space between the nozzle and discharge tube and carries with it by adhesion the air from the bulb, which is continually replaced by air from the vessel being exhausted.

It is necessary to securely fasten the ends of the rubber tube connected with the tap, or the water pressure may force it off, thus causing the breaking of the instrument. To secure the best effects with this pump, it is necessary to connect a vertical tube 25 to 30 feet long with the discharge end of the pump.

The metallic aspirator shown in Figs. 105, 106, and 107 is of course free from all danger of being broken in use, and it has other qualities which render it superior to the glass instrument, one of which is a much higher efficiency, another is its ability to retain the vacuum should the flow of water be accidentally or purposely discontinued. It can be screwed directly on the water tap, and needs no additional pipe to cause it to work up to its full capacity; and where a head of water is not available, it may be inserted in a siphon having a vertical height of ten feet or more.

Fig. 105.



Chapman's Aspirator.

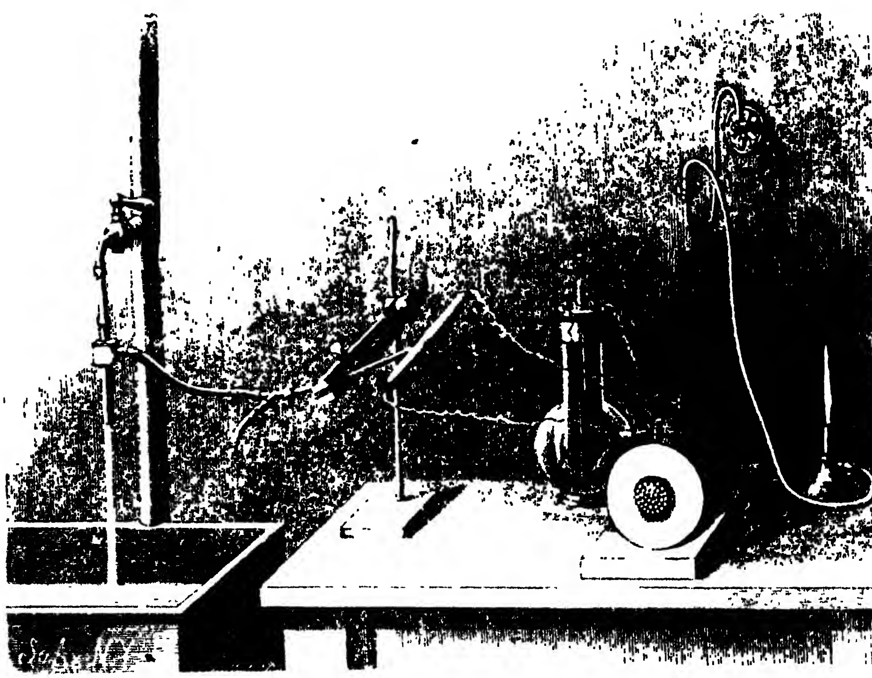
This instrument is known as the Chapman aspirator. Like all instruments of its class, it is based on the principle of the Giffard injector. The construction of the aspirator is shown in section in Fig. 105. The water enters at A, as indicated by the arrow. The air enters at B, and both air and water are discharged at C. The water in going through the contracted passage forms a vacuum at the narrower part into which the air enters. The starting of the instrument is facilitated by a diaphragm which half closes the discharge tube. The water is prevented from entering the air pipe by a small check valve shown in the interior of the lateral tube. Much of the efficiency of this instrument is due to the accuracy with which the contracted passage is formed. A

slight change in the shape of this passage seriously affects the results.

The vacuum produced by this aspirator is equal to that of the mercurial barometer, less the tension of aqueous vapor. That is to say, when the barometer is at 30 inches, the vacuum produced by the aspirator will be about 29½ inches. Such a vacuum can be produced by water under a pressure of five and one-half pounds.

In Fig. 106 is shown the aspirator applied to a Geissler

Fig. 106.



Exhausting Geissler Tube.

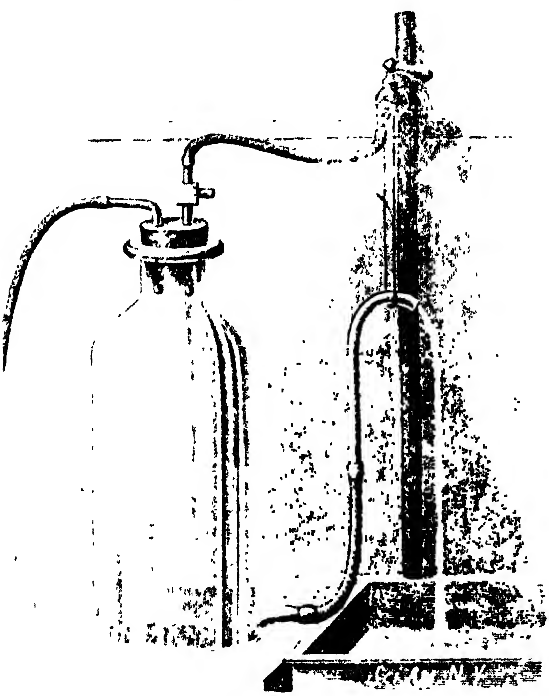
tube. It quickly exhausts an 8 inch tube, so that the discharge of an induction coil will readily pass through. By placing a tee in the connecting pipe, the Geissler tube can be filled with different gases. Each will exhibit its peculiar color as the spark passes. The vacuum is not high enough for a perfected Geissler tube, but it is sufficient for the greater part of vacuum experiments. The aspirator can be arranged to produce a continuous blast sufficient for the

operation of a blowpipe, and for other uses requiring a moderate amount of air or gas under pressure.

The method of accomplishing this is illustrated in Fig. 107. The instrument is arranged to discharge into a bottle or other vessel having an overflow, and the air for the blast is taken out through the angled tube inserted in the stopper of the bottle. The amount of air pressure is regulated by the water pressure and the height of the overflow pipe.

For many vacuum experiments a plate provided with a

FIG. 107



Blast produced by the Aspirator

FIG. 108.

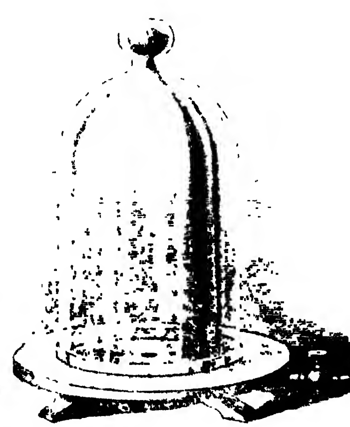


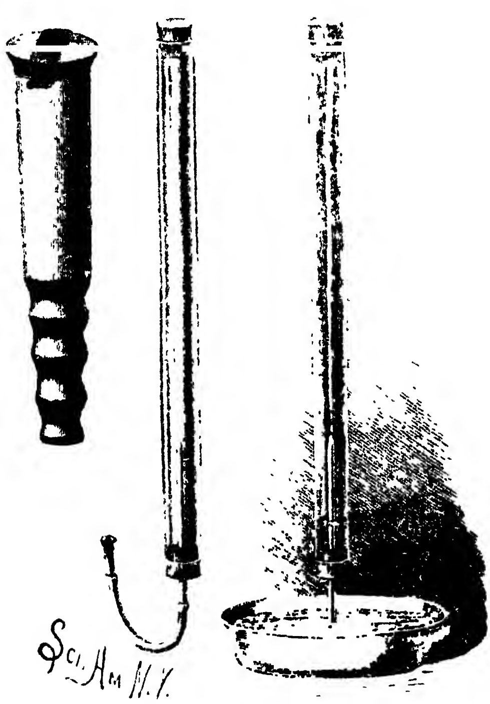
Plate and Receiver for Aspirator

central aperture, and having a tube extending from the aperture to the edge of the plate, will be found useful. The tube is provided with a suitable valve, which closes communication with the aspirator, and which also serves to admit air, when required, to the receiver fitted to the plate. This plate and various accessories are like the plate and accessories of a piston air pump. Communication is established between the tube of the plate and the aspirator by means of a pure rubber tube, which is practically air-tight.

MOUTH VACUUM APPARATUS.

Although the vacuum apparatus already described is very simple, it is quite practicable to perform many experiments of this class by using the mouth as an air pump, thus dispensing almost entirely with mechanism. The operation of producing a partial vacuum is facilitated by employing a valve such as is shown in the left hand figure of Fig. 109. This valve consists of a thick tube of hard wood, having a bore of about $\frac{1}{16}$ inch. One end of the tube is corrugated to receive a rubber pipe, and over the other end is tied a valve of elastic rubber. By connecting this valve with a stopped glass tube by means of a flexible rubber pipe and a jet tube in the manner shown, and then sucking the air through the valve, a partial vacuum may be quickly formed in the tube. The vacuum will be retained by the valve, so that when the valve is disconnected from the jet tube, while the latter is immersed in water, the pressure of the external air will cause the water to enter the glass tube through the jet in the form of a fountain. It is obvious that many of the foregoing experiments may be tried in a similar way.

FIG. 109.



Mouth Vacuum Apparatus.

ANCIENT INVENTIONS OPERATED BY AIR PRESSURE.

More than two thousand years ago, Hero (or Heron), a philosopher and mathematician of Alexandria, invented the fountain shown in the annexed engraving. This device,

FIG. 110.

Hero's Fountain.

because of its antiquity, as well as its simplicity and completeness, is very interesting and instructive.

As represented in the engraving, it may be classed with toys, or at most regarded as only an apparatus for illustrating a scientific principle; but it is more than this. It is the progenitor of a number of modern inventions for raising water and producing air pressure.

The curious feature of the apparatus is that it apparently causes the water to rise above its own level by its own pressure, but such is not the case. Its action is due to the transference of the pressure of one column of water to another column of water at a higher level, through the medium of a column of confined air. It is as truly a case of the application of external power as it would be if a steam air compressor were applied.

The water to be elevated is contained by the upper bulb, which communicates at its lower side with the fountain nozzle, and at its upper side with the downwardly curved tube connecting with the top of the lower bulb. A tube connecting with the lower side of the lower bulb extends upward to the level of the upper bulb, and terminates in a flaring cup.

The upper bulb having been filled with water and the lower bulb with air, the fountain is started by pouring a small quantity of water into the cup, which by flowing downward through the tube connected with the cup exerts a pressure on the air contained by the lower bulb. This pressure is equal to the weight of the column of water in the tube. The air pressure thus created is transferred to the top of the upper bulb by the air column rising from the lower bulb through the tube connecting the two bulbs, so that the pressure of the water column descending from the cup, less a very small allowance for friction, is effective in forcing the water out of the upper bulb through the fountain nozzle.

The proper inclination of the apparatus directs the water jet so that the water falls into the cup and replaces the water used in creating the air pressure in the lower bulb.

When the lower bulb is filled with water, and the water has been entirely discharged from the upper bulb, the action

of the apparatus ceases; but it may be [illegible] inverting the fountain, allowing the water in the [illegible] run into the upper or water bulb, then righting it and [illegible] pouring a little water into the cup.

This device was employed during the last century for elevating water in the mines of Hungary.

In Fig. 111 is shown an interesting modification of Hero's fountain. The apparatus is made of glass, to illustrate the principle on which it operates. It consists of a volute coil of tubing connected at its center with a hollow shaft that communicates with a hollow journal box, from which a stand-pipe rises. When this coil is turned in the direction indicated by the arrow, water and air assume in the coiled tube positions relative to each other as shown in the engraving; the water being arranged in a series of curved columns on one side of the center of the wheel, the air being correspondingly disposed on the opposite side of the center. The height to which the water will be raised by this machine is equal to the sum of the heights above their upwardly curved lower ends of all the curved columns of water contained by the coil. It will be noticed that the pressure of one curved column of water in the coil is communicated to the next through the intervening air, which weighs practically nothing.

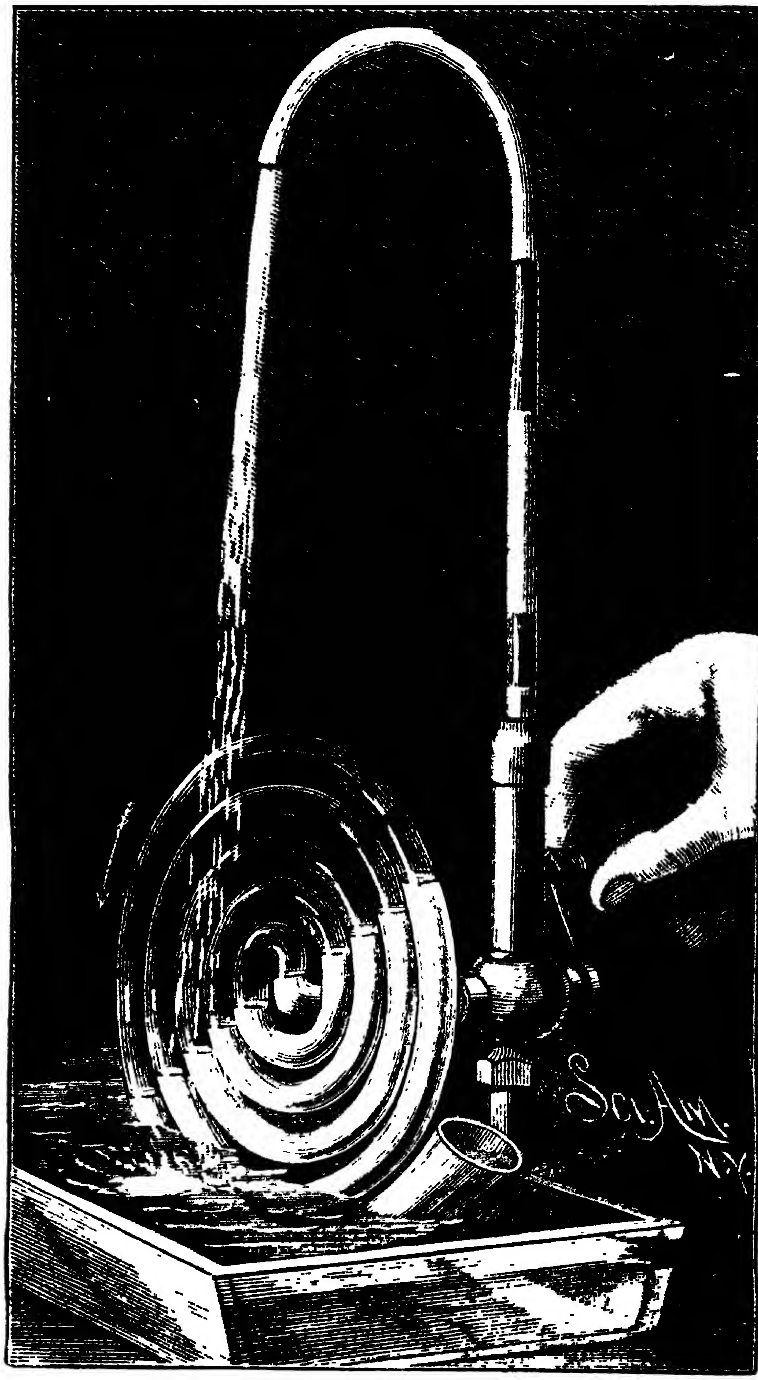
This machine was invented by Wirtz, of Zurich, in 1746. "In 1784 a machine of this kind was made at Archangelsky that raised a hogshead of water in a minute to an elevation of 74 feet, and through a pipe 760 feet long."

INERTIA OF AIR.

Although air is a light and extremely mobile fluid, it has sufficient inertia to permit of the flight of birds, the operation of windmills, and the propulsion of sailing vessels. The aerial top shown in Fig. 112 is dependent upon the inertia of the air. This top is simply a metallic screw wheel, adapted to be revolved by means of a string in the same manner as an ordinary top.

With the application of a sufficient amount of force, this top will rise to a height of 150 to 200 feet. It can hardly be

FIG. 111.

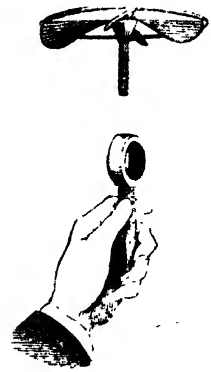


Wirtz's Pump.

called a flying machine, as it does not carry its own motive power. In the next illustration, however, is shown a flying machine which in one sense carries its own power, that is, stored power.

It consists of a light frame furnished at one end with a slender rattan bow inclosed in a little bag of tissue paper, which forms a sort of rudder when the fly-fly ascends, and opens like an umbrella when it descends, forming a parachute, which greatly retards the fall. In the crosspiece of the opposite end is journaled a little shaft formed of a wire having on its inner end a loop receiving a number of rubber bands, which are fastened to the opposite end of the frame. To the outer end of the little shaft is secured a piece of cork, in which are inserted two feathers inclined at an angle with the plane of the shaft's rotation, and oppositely arranged with respect to each other.

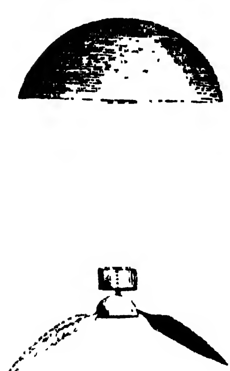
FIG. 112.



Aerial Top.

By turning the propeller wheel thus formed, the rubber bands are twisted, and sufficient power is stored in them to turn the propeller wheel in the direction opposite to that required for winding, and thus propel the device through the air.

FIG. 113.



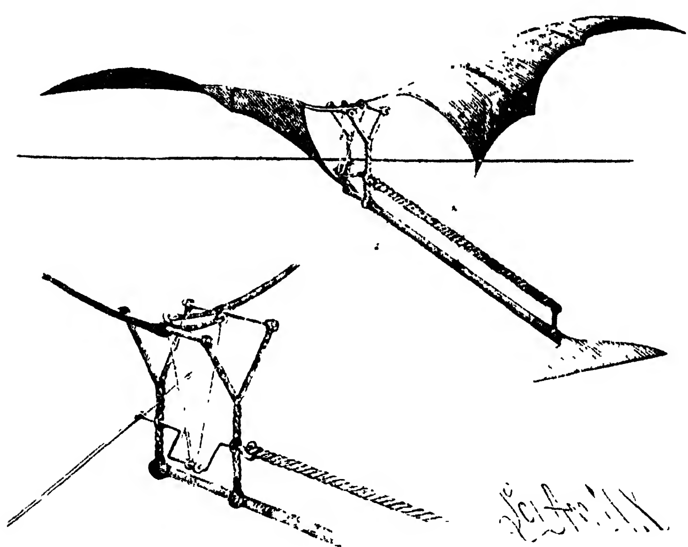
The Fly-Fly.

Another device still more nearly approaching the ideal flying machine is shown in the annexed cut, Fig. 114 being a perspective view of the entire bird, and Fig. 114*a* an enlarged perspective view of the working parts. It is known as Penaud's mechanical bird.

It is a pretty toy, imitating the flight of a bird very well indeed. It soars for a few seconds, and then requires rewinding. Two Y-shaped standards secured to the rod forming the backbone of the apparatus support at their upper ends two wires, upon which are pivoted two wings formed of light silk. The wings are provided with light

stays, and are connected at their inner corners with the backbone by threads. In the Y-shaped standards is journaled a wire crank shaft carrying at its forward end a transverse wire forming a sort of balance, and serving also as a key for winding. The inner end of the crank shaft is provided with a loop to which are attached rubber bands which are also secured to a post near the rear end of the apparatus. Two connecting rods placed on the crank are pivotally connected with the shorter arms of the levers of the wings. The rear end of the backbone is provided with a rudder.

FIGS. 114 AND 114a.



Mechanical Bird.

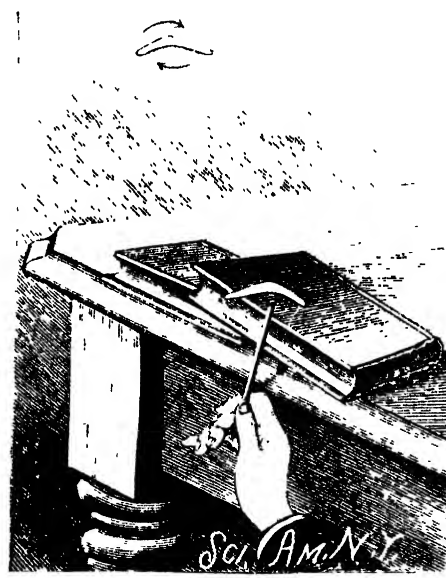
The rubber bands are twisted by turning the shaft by means of the cross wire. When the shaft is released, it is turned by the rubber bands in a reverse direction, causing the crank to oscillate the wings, which beat the air in a natural manner, and propel the device forward. The principle of the inclined plane is involved here, but the plane, instead of being rotated, as in all the cases mentioned above, is reciprocated.

The toy boomerang, which is, in some respects, similar to the regular article, cannot perform all the feats with

which the more pretentious implement is credited; but it can be projected, and made to return over nearly the same path.

The toy boomerang is made of a piece of tough cardboard cut on a parabolic curve as shown in the engraving, one arm of the boomerang being a little longer than the other. When laid on an inclined surface, as shown in the engraving, and snapped by a pencil held firmly in one hand and drawn back and released by the fingers of the other hand, the boomerang is set in rapid rotation by the blow, and is at the same time projected, the first part of the trajectory being practically in the continuation of the plane in which the boomerang is started; but when the momentum which carries it forward is exhausted, the boomerang still revolves, and maintains its plane of rotation, so that when it begins to fall, instead of describing the same trajectory as ordinary projectiles, it makes a circuit to one side and comes back toward the point of starting. The flatness or curvature of the boomerang and the form of its edges, as well as the position in which it is placed for starting, and the speed and manner of starting, all have an effect in determining the outward as well as the return course of the projectile.

FIG. 115.



Boomerang

VORTEX MOTION.

Every one has noticed the symmetrical wreaths of smoke and steam occasionally projected high into the air on a still day by a locomotive; similar rings may often be noticed after the firing of a gun. It is not uncommon to see a

smoker forming such wreaths with his mouth. These rings are simply whirling masses of air revolving upon axes curved in annular form, the smoke serving to mark the projected and whirling body of air, thus distinguishing it from the surrounding atmosphere. The whirls would exist without the smoke, but they would, of course, be invisible.

FIG. 110.

Vortex Rings.

All the apparatus needed for producing vortex rings at will is an ordinary pasteboard hat box, having a circular hole of 4 or 5 inches diameter in the cover. Two pads of blotting paper are prepared, each consisting of six or eight pieces. Upon one pad is poured a small quantity of muriatic acid and upon the other a similar quantity of strong aqua

ammonia. These pads are placed in the box and immediately a white cloud is formed, which consists of particles of chloride of ammonium so minute as to float in the air.

By smartly tapping opposite sides of the box, a puff of air is sent through the circular opening of the cover, carrying with it some of the chloride of ammonium. The friction of the air against the edges of the cover retards the outer portion of the projected air column, while the inner portion passes freely through, thus imparting a rotary motion to the body of air adjoining the edge of the cover, the axis of revolution being annular. After the ring is detached, the central portion of the air column continues to pass through it, thus maintaining the rotary motion.

When two rings are projected in succession in such a manner as to cause one to collide with the other, they behave much like elastic solid bodies. By making the aperture in the box cover elliptical, the rings will acquire a vibratory motion.

By fastening the box cover loosely at the corners, the box may be turned upon its side and rings may be projected horizontally.

It is obvious that smoke may be used in this experiment in lieu of the chloride of ammonium.

CHAPTER VIII.

SOUND.

The student of acoustics need not go beyond the realm of toys for much of his experimental apparatus. The various toy musical instruments are capable of illustrating many of the phenomena of sound very satisfactorily, if not quite as well as some of the more pretentious apparatus.

Sound is a sensation of the ear, and is produced by sonorous vibrations of the air. It may be in the nature of a mere noise, due to irregular vibrations, like the noise of a wagon on the street, or it may be a sharp crack or explosion, like the cracking of a whip or like the sound produced by the collision of solid bodies. The clappers, or bones, with which all boys are familiar, are an example of a class of toys which create sound by concussion, and the succession of sounds produced by the clappers are irregular, and clearly distinct from musical sounds. A succession of such sounds, although occurring with considerable frequency and perfect regularity, will not become musical until made with sufficient rapidity to bring them within the perception of the ear as a practically continuous sound. The rattle, or cricket, produces a regular but unmusical sound.

Clappers.

The wooden springs of the cricket snap from one ratchet tooth to another, as the body of the cricket is rapidly swung around, making a series of regular taps, which, taken all

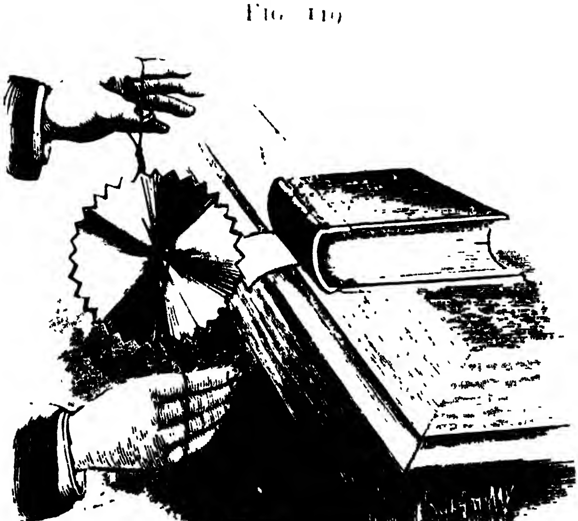
together, make a terrific noise, having none of the characteristics of musical sounds. That a musical sound may be made by a series of taps is illustrated by the buzz, a toy consisting of a disk of tin having notched edges and provided with two holes on diametrically opposite sides of the center, and furnished with an endless cord passing through the holes. The disk is rotated by pulling in opposite directions on the twisted endless cord, allowing the disk to twist the cord in the reverse direction, then again pulling the cord, and so on.

FIG. 118.

The Cricket, or Rattle

If, while the disk is revolving rapidly, its periphery is brought into light contact with the edge of a piece of paper, the successive taps of the teeth of the disk upon the paper produce a shrill musical sound, which varies in pitch according to the speed of the disk. Such a disk mounted on a shaft and revolved rapidly is known as Savart's wheel.*

FIG. 119.



The Buzz

It is ascertained by these experiments that regular vibrations of sufficient frequency produce musical sounds, and that concussions, irregular vibrations, and regular vibrations having a

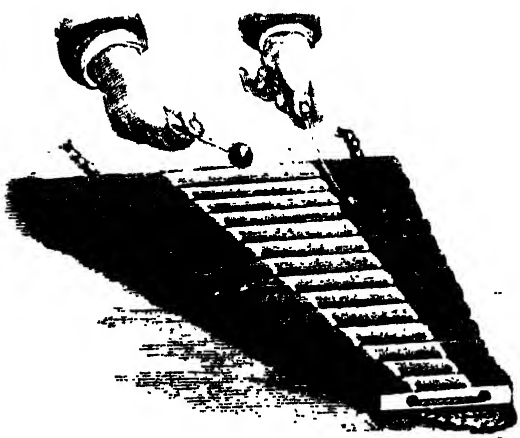
* See chapter on experiments with the scientific top.

slow rate, produce only noises. It has been determined that the lowest note appreciable by the ear is produced by sixteen complete vibrations per second, and the highest by 24,000 complete vibrations per second.

VIBRATING RODS.

The zylophone and metallophone are examples of musical instruments employing free vibrating rods supported at their nodes. The zylophone consists of a series of wooden rods of different lengths, bored transversely at their nodes, or points of least vibration, and strung together on cords. The instrument may either be suspended by the cords or

Fig. 128.



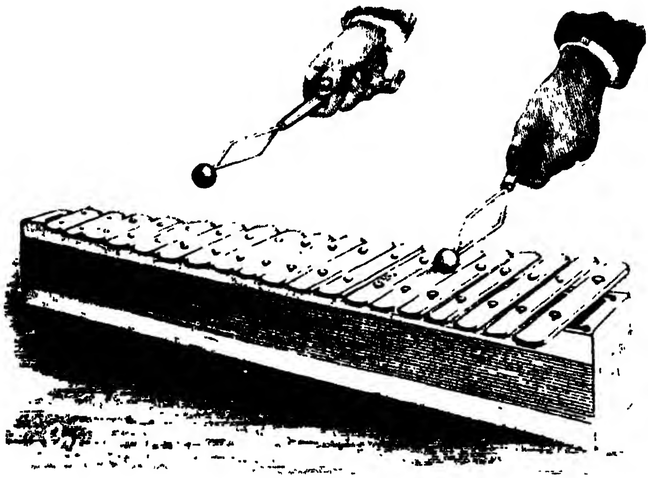
The Zylophone.

laid upon loosely twisted cords situated at the nodes. By passing the small spherical wooden mallet accompanying the instrument over the wooden rods, very agreeable liquid musical tones are produced by the vibration of the rods, and when the rods are struck by the mallet they yield tones which are very pure, but not prolonged.

The cheaper forms of zylophone are tuned by slitting the rods transversely at their centers on the under side, by means of a saw, to a depth required to give them the flexibility necessary to the production of the desired tones. The rods are divided by the nodes into three vibrating parts,

the parts between the rodal points and the ends being nearly one-half of the distance between the nodes.

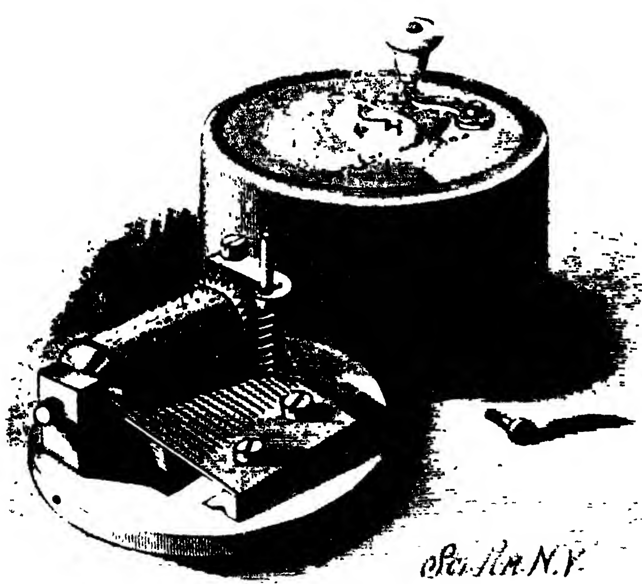
FIG. 121.



The Metallophone

The metallophone is similar in form to the zylophone, but, as its name suggests, the vibrating bars are made of metal—

FIG. 122.



Music Box

hardened steel. The bars rest at their nodes on soft woolen cords, secured to the upper edges of a resonator forming

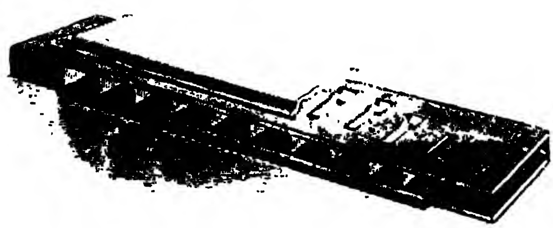
the support of the entire series of bars. The resonator is tapered both as to width and depth, and serves to greatly increase the volume of sound, although it does not act as a perfect resonator for each bar.

When a bar is struck, its downward movement produces an air wave which moves downward, strikes the bottom of the resonator, and is reflected upward in time to re-enforce the outwardly moving air wave produced by the upward bending of the bar.

The metallophone yields sweet tones which are quite different in quality from those produced by the vibration of wooden bars.

The music box furnishes an example of the class of instruments in which musical sounds are produced by the vibra-

FIG. 123.



Mouth Organ, or Harmonica.

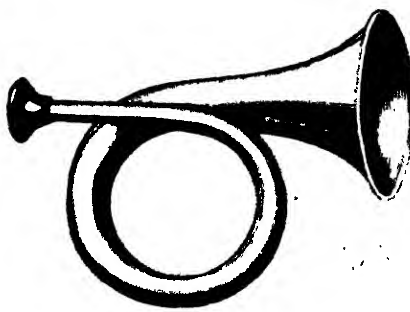
tion of free reeds or tongues rigidly held at one end and free to vibrate at the other end. The tongues of the music box are made by slitting the edge of a steel plate, forming a comb, which is arranged with its teeth projecting into the paths of the pins of the cylinder, which are distributed around and along the cylinder in the order necessary to secure the required succession of tones. The engagement of one of the pins of the cylinder with one of the tongues raises the tongue, which, when liberated, yields the note due to its position in the comb.

The tongues are tuned by filing or scraping them at their free or fixed ends, or by loading them at their free ends. In this instrument the sonorous vibrations are produced by the tongue, which itself has the desired pitch.

REEDS.

In reed instruments the sounds emitted by the reeds are greatly strengthened by resonance. The mouth organ or harmonica is a familiar example of a simple reed instrument without accurately adjusted resonators.

Fig. 124.



The Bugle.

When reeds are employed in connection with resonating pipes, as in the case of the reed pipes of an organ, the pipe synchronizes with the reed, and re-enforces the sound. When the reed is very stiff, it commands the vibrations of the air column, and when it is very flexible, it is controlled by the air column.

The horn is a reed instrument in which the lips act as reeds, and the tapering tube serves as a resonator.

Fig. 125.

Longitudinal Vibration of a Steel Rod.

LONGITUDINAL VIBRATION OF RODS.

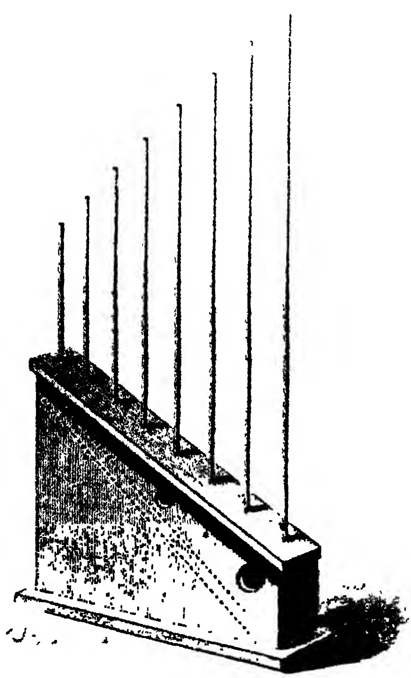
The foregoing are examples of the transverse vibration of rods. The annexed figures illustrate apparatus in which the longitudinal vibration of rods is shown.

By grasping a steel rod at the center between the thumb and finger, each of its two ends being free, and striking it upon the end with a hammer, the rod can be made to yield a sound of very high pitch. By holding one end firmly in a vise, and skillfully rubbing the rod, by pulling it

between the fingers with a cloth or piece of leather covered with powdered resin, a note an octave lower will be emitted.

Marloye's harp, shown in Fig. 126, depends upon the longitudinal vibration of rods. This instrument consists of a number of pin rods of different lengths inserted in a sounding box or solid block of wood, and tuned by cutting them off at such lengths as to cause them to yield the notes of the diatonic scale. The instrument is played by rubbing the rods lengthwise by the thumb and finger covered with powdered resin. The sounds produced by the instrument resemble those of a flute.

FIG. 126

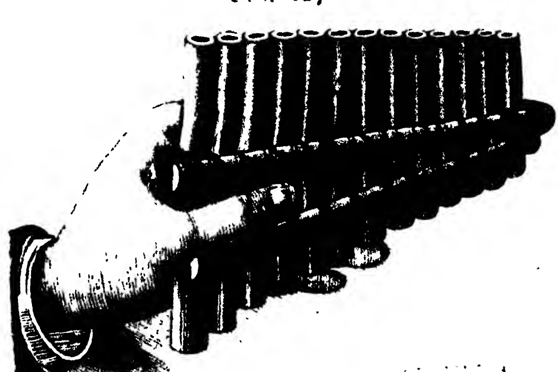


Marloye's Harp.

PIPES.

The ancient Pandean pipes present an example of an instrument formed of a series of stopped pipes of different lengths. These pipes

FIG. 127



Pandean Pipes.

are tuned by moving the corks by which their lower ends are stopped, and the air is agitated by blowing across the

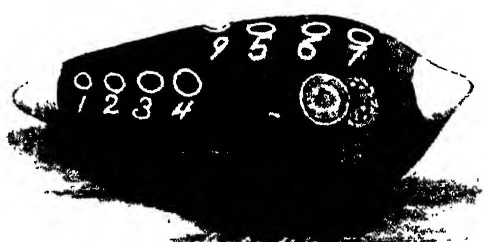
end of the tubes. The flageolet is an open pipe in which the air is set in vibration by blowing a thin sheet of air through the slit of the mouthpiece against the thin edge of the opposite side of the embouchure. The rate of the fluttering produced by the air striking upon the thin edge is determined by the length of the pipe of the instrument, the length being varied to produce the different notes, by open-

Fig. 128.

Flageolet.

ing or closing the finger holes. By comparing the flageolet with the Pandean pipes, it is found that for a given note the open flageolet pipe must be about twice as long as the Pan pipe. When all the finger holes of the flageolet are closed, it is then a simple open pipe, like an organ pipe, and, if compared with the Pan pipe yielding the same note, it is found to be just twice as long as the closed pipe. If, while

Fig. 129.



Ocorina.

the holes are closed, the open end of the flageolet pipe be stopped, the instrument will yield a note an octave *lower* if the blowing be very gentle. These experiments show that the note produced by a stopped pipe is an octave below the note yielded by an open pipe of the same length, and the same as that obtained from an open pipe of double the length.

The ocorina is a curious modern instrument, of much

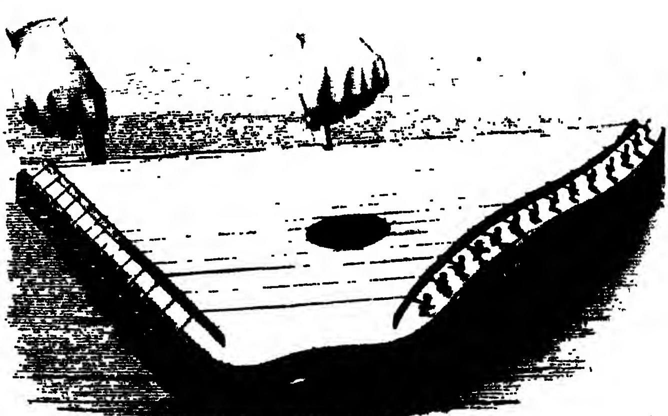
the same nature as the flageolet. It is, however, a stopped pipe, and shows how tones are modified by form and material, the latter being clay. It produces a mellow tone, something like that of a flute.

STRINGED INSTRUMENTS.

The zither, now made in the form of an inexpensive and really serviceable toy, originated in the Tyrol. It consists of a trapezoidal sounding board, provided with bridges, and having 24 wire strings.

Its tones are harp-like, and with it a proficient player can produce agreeable music. Much of the nature of the

Fig. 13.



Zither.

vibration of strings may be exhibited by means of this instrument. On damping one of the strings by placing the finger or a pencil lightly against its center, and vibrating the string, at the same time removing the pencil, the string will yield a note which is an octave higher than its fundamental note.

By examining the string closely, it will be ascertained that at the center there is apparently no vibration, while between the center and the ends it vibrates. The place of least vibration at the center of the string is the node, and between the node and the ends of the strings are the centers. It will thus be seen that the string is practically divided into two equal vibrating segments, each of which produces

a note an octave higher than that of the open string. That the note is an octave higher than the fundamental note may be determined by comparing it with the note of the string which is an octave above in the scale of the zither.

By damping the string at the end of one-fourth of its length, the remaining portion of the string divides itself into three ventral segments, with two nodes between.

The division of the string into nodes and venters occurs whenever the string is vibrated, and all of the notes other than the fundamental are known as harmonics, and impart to the sound of the string its quality.

By tuning the first two strings in unison, the vibration of one string by sympathy with the other string may be shown.

CONDUCTION OF SOUND.

The string telephone, although not a musical instrument, nor even a sound producer, exhibits an interesting feature in the conduction of sounds. It consists of two short tubes or mouthpieces, each covered at one end with a taut parchment diaphragm, the two diaphragms being connected with a stout thread. By stretching the thread so as to render it taut, a conversation may be carried on over quite a long distance, by talking in one instrument and listening at the other. The vibration of one diaphragm, due to the impact of sound waves, is transmitted to the other diaphragm by the thread.

Fig. [illegible].

String Telephone.

In the toys illustrated we have a representative of the Savart's wheel in the buzz; of the pipe organ in the Pan pipes, the flageolet, and the mouth organ; of band instruments in the bugle; and of the piano, harp, and other stringed instruments in the zither.

HARMONIC VIBRATIONS.

Impulses which, occurring singly or at irregular intervals, are incapable of producing any noticeable effects may, when made regularly, under favorable circumstances, yield astonishing results. The rattling of church windows by air waves generated by a particular pipe of the organ, a bridge strained or broken by the regular tramp of soldiers or by the trotting of horses, the vibration of a six or eight story building by a wagon rumbling over the pavement, a factory, vibrated to a dangerous degree by machinery contained within its walls, a mill shaken from foundation to roof by air waves generated by water falling over a dam, are all familiar examples of the power of regular or harmonic vibrations.

Harmonic vibrations result from regularly recurring impulses, which may be very slight indeed, but when the effects of the impulses are added one to another, the accumulation of power is sometimes very great.

To secure cumulative effects, the impulses must not only be regular in their occurrence, but the body receiving the impulses must be able to respond, its vibratory period must correspond with the period of the impulses, and, further than this, the impulses must bear a certain relation to a particular phase of the vibration, in order that they may act upon the vibrating body in such a way as to augment its motion rather than diminish it.

There are railroad bridges that vibrate alarmingly when crossed by locomotives running at a certain speed, the vibrations being caused by the comparatively slight lack of balance in the driving wheels and connecting rods. For this reason the speed is restricted on such bridges.

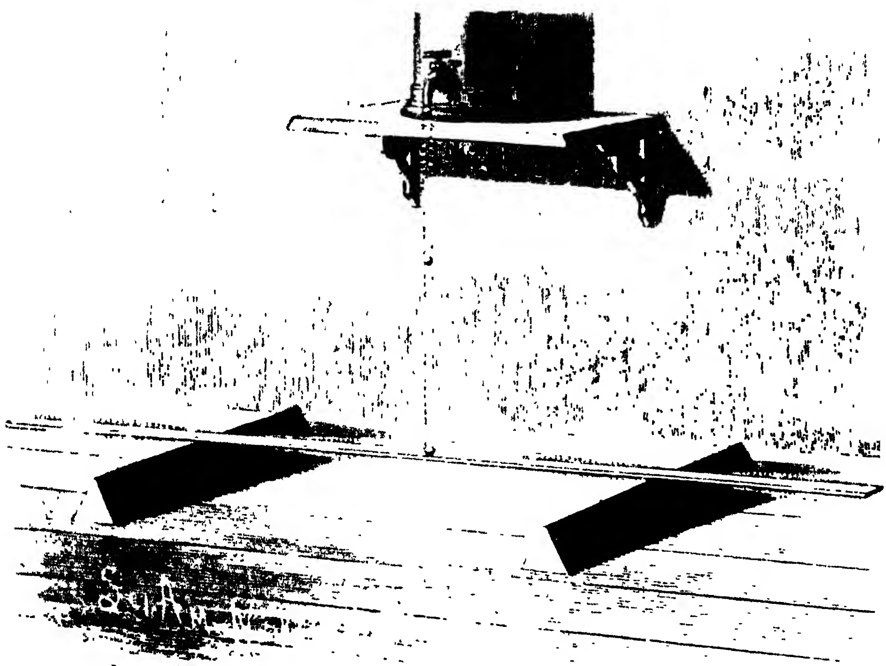
During the early tests of the East River bridge between New York and Brooklyn, it was found that the structure was so massive and its vibratory period so slow that it could not be injuriously affected by the marching of men or the trotting of horses; consequently, travel proceeds on this bridge as upon any highway.

A well known English physicist is reported to have said

that with suitable appliances he could break an iron girder by pelting it with pith balls. An experiment of this kind would certainly show in a striking manner the effects of very slight rhythmic impulses. As it is manifestly impracticable to perform such an experiment, an easier method of illustrating harmonic vibrations must be sought.

In the accompanying engravings, Fig. 132 shows how a bar of steel may be set in active vibration by drops of water. The bar is supported at nodal points upon angular pieces

FIG. 132

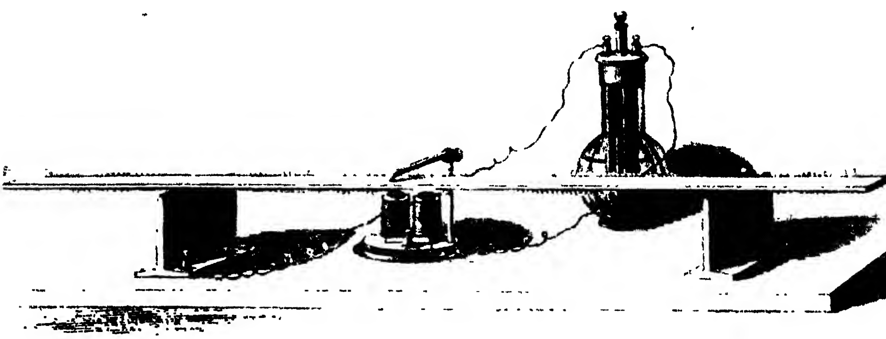


Harmonic Vibration.

of wood. Above the center of the bar is arranged a faucet, which communicates with the water supply. The bar is first vibrated by hand, and the faucet is adjusted so that the water drops in unison with the vibrations of the bar. The motion of the bar is then stopped, and the water is allowed to drop on it. The bar soon begins to vibrate, and in a short time the vibration acquires considerable amplitude. In Fig. 133 is shown an experiment in which the intermittent pull of an electro-magnet is made to accomplish the

same thing. In this case the steel bar forms a part of the circuit. The magnet is provided with a light wooden spring-pressed arm, carrying a contact point and a conductor. This arm is arranged to follow the bar up and down through the upper half of its excursion, breaking the contact at the median position of the bar. The magnet becomes alternately magnetized and demagnetized, and the bar is alternately pulled down and released. The bar used in these experiments is ¼ inch thick, 1¼ inches wide, and 8 feet

Fig. 133.



Vibration by Magnetic Impulse.

long. A much larger bar might be used. Without doubt, even an iron girder of great size and weight might be set in active vibration by the same means.

SIMPLE SOUND RECORDER.

In Fig. 134 is shown a simple device for recording sounds autographically.* The propelling of the smoked plate under the stylus is accomplished by simply inclining the support of the plate and allowing the plate to slide off quickly by its own gravity.

This apparatus consists of a wooden mouthpiece like that of a telephone, with a parchment diaphragm glued to its back, and provided with a tracing point, which is slightly inclined downward toward the guide for the plate.

This tracing point is a common sewing needle, having its pointed end bent downward. It is cemented at the eye end

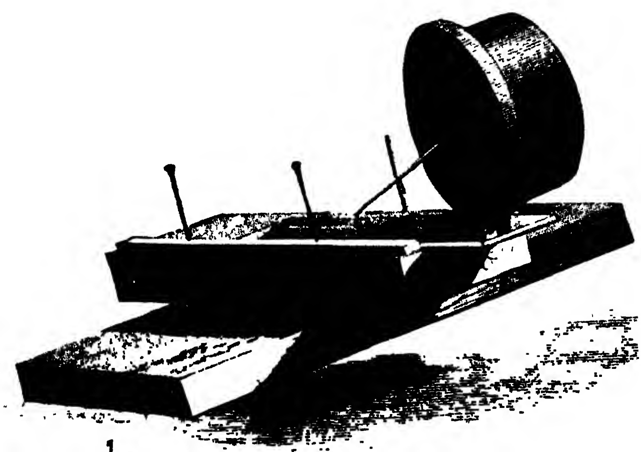
* See also chapter on projection.

to the center of a diaphragm by a drop of sealing wax. The mouthpiece is attached to a base supporting the cross-piece upon which the smoked plate is placed.

A thin strip of wood fastened by two common pins—one at each end—serves as a guide for the smoked plate.

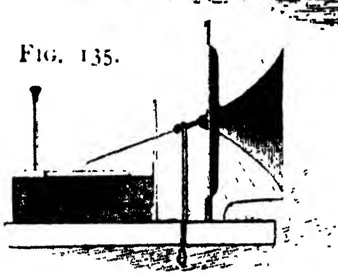
To prevent the tracing point from being deflected laterally by the moving glass, a needle is driven down into the baseboard in contact with the tracing point.

Fig. 134.



Recorder for Sound Vibrations.

Fig. 135.



A very thin rubber band is slipped over the tracing point and drawn down through a small hole in the baseboard, as shown in Fig. 135, until the necessary tension is secured for keeping the point in delicate but continuous contact with the smoked plate.

The best plates for the purpose of making the tracings are the microscope slide glasses with ground edges. They may be readily smoked over a gas jet turned down quite small, or over a candle or kerosene lamp. The flame in any case should be small and the film of smoke fine and very thin.

The smoked plate is placed on the support and against the guide and under the needle, and the instrument is inclined until the plate rests against the guide. Now the

mouth is placed near the mouthipece, and a vowel is uttered, while the instrument is inclined sidewise at a sufficient angle to permit the glass to slide off quickly. Of course the glass should fall only a very short distance, and it is well to provide a soft surface for it to alight on.

If all this is done with the slightest regard for precision, a beautiful tracing will be secured, which will show the composite nature of each sound wave. The regularity and uniformity of the entire tracing is surprising, considering the comparatively crude means employed in producing it.

The beginning of the sinuous line is somewhat imperfect, owing to the slow initial movement of the plate in its descent, but the greater portion is perfect.

After having made one line, the pins holding the guide are moved forward, placing the guide in a new position, when the operation of tracing may be repeated with another vowel. Monosyllables and short words may be recorded. If the plate is made long enough, it will, of course, receive an entire sentence.

These tracings may be covered with a second microscopic glass plate to protect them, or they may be mounted as a microscopic object for a low power by putting a thin cover over them in the usual way. Used as lantern slides, they give fine results.

VIBRATING FLAMES.*

The most perfect exhibition of vibrating flames can be made only with expensive apparatus; but the student can get very satisfactory results by the employment of such things as are shown in Fig. 136. A candle, a rubber tube, an oblong mirror, and a piece of thread are the only requisites, excepting the support for the mirror—which in the present case consists of a pile of books—and a little paper funnel inserted in the end of the rubber tube and forming the mouthpiece.

The thread is tied around opposite ends of the oblong mirror, and the mirror supported by passing the thread through the upper book of the pile, which juts over to allow

* See also chapter on experiments with scientific top.

the mirror to swing freely without touching the books. The mirror is made to vibrate in a horizontal plane by giving it a twisting motion. One end of the rubber tube is placed very near the base of the candle flame, and the other end, which is provided with the paper mouthpiece, is placed before the mouth and a sound is uttered which causes the air contained by the rubber tube to vibrate and impart its motion to the candle flame. The vibratory character of the flame is not noticeable by direct observation, but on viewing the flame in the swinging mirror, separate images of

FIG 136.

Simple Method of Producing and Viewing Vibrating Flames.

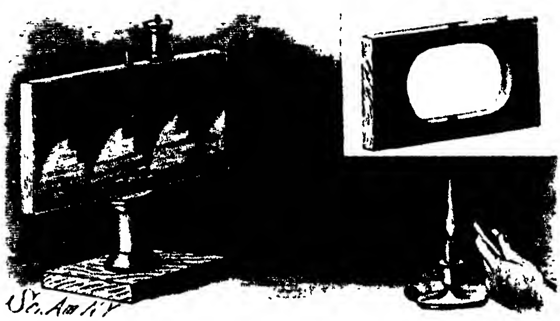
the flame will be seen. These images are combined in a series which, with a certain degree of accuracy, represent the sound waves by which the fluctuations of the flame are produced.

To show that these images result from a vibrating flame, it is only necessary to view the flame in the mirror. When no sound is made in the mouthpiece, only a plain band of light will be seen.

A somewhat more convenient arrangement of mirrors is shown in Fig. 137. In a baseboard is inserted a wire, one-eighth inch or more in diameter and about a foot long. On

this wire is placed an ordinary spool, and above the spool a thin apertured board (shown in the detailed view), the board being about 8 inches long and 6 inches wide. The board is perforated edgewise to receive the wire. In the upper edge of the board, half way between the center and end, is inserted a wire, upon which is placed a small spool, serving as

Fig. 137.



Rotating Mirror.

a crank by which to turn the board. Upon opposite sides of the board are placed mirrors of a size corresponding to that of the board, the mirrors being secured to the board by strips of paper or cloth pasted around the edges. The image of the flame is viewed in the mirrors as they are revolved.

SPEAKING FLAME.

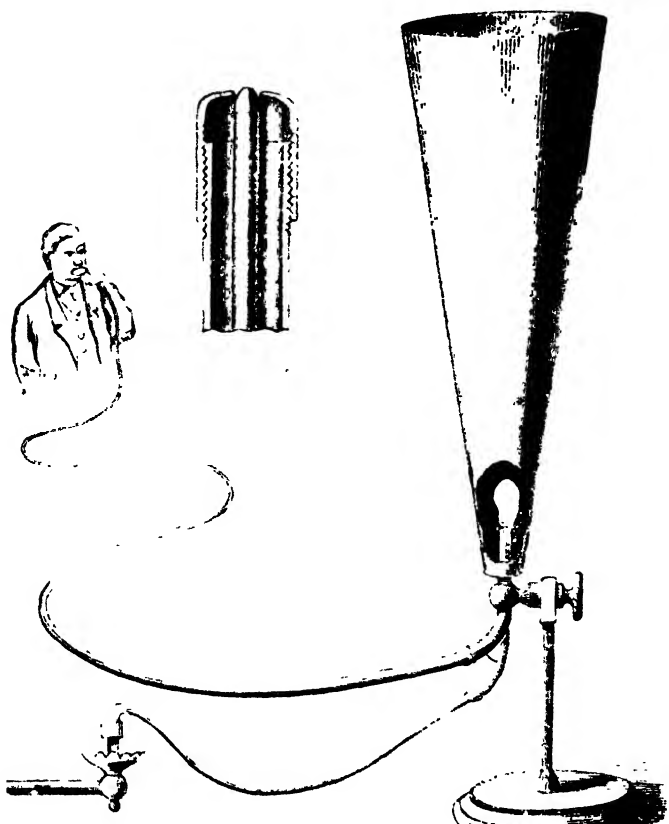
The speaking flame apparatus shown in the annexed engravings is based on the principle of the annular burner often used in producing the oxyhydrogen light, the principal difference being in the diminished annular orifice. The construction of the burner is clearly shown in Fig. 138, the detached illustration being an enlarged sectional view of the end of the burner. Gas is taken through the central tube, and the flexible speaking tube is connected with the outer tube of the burner. When the apparatus is used for producing musical and articulate sounds, a resonator is attached, as shown in Fig. 138. In this figure the resonator is broken away to show its position relative to the burner.

By screwing the cap of the burner up or down, an adjust-

ment may be secured which will cause the flame to reproduce any sounds uttered in the mouthpiece attached to the flexible speaking-tube. With a fine adjustment articulate speech or any note of the musical scale within the compass of the human voice may be reproduced by the flame.

The slight air waves which reach the burner through the flexible pipe act directly upon the base of the flame; this

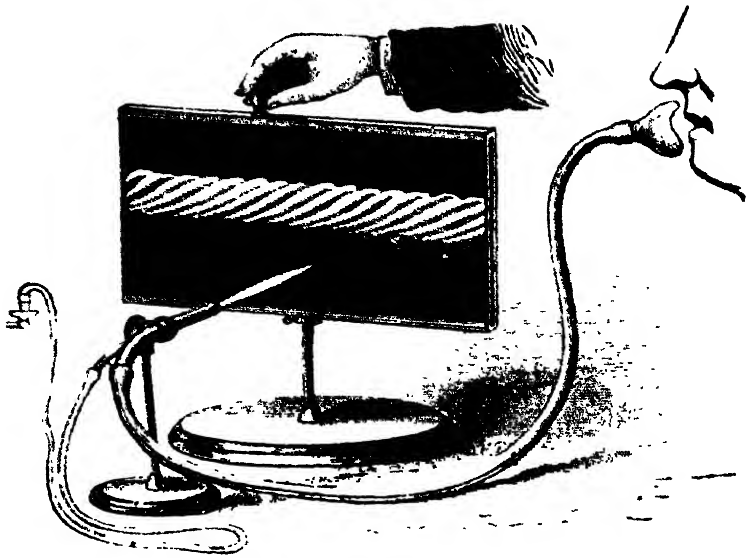
FIG. 138.



The Speaking Flame.

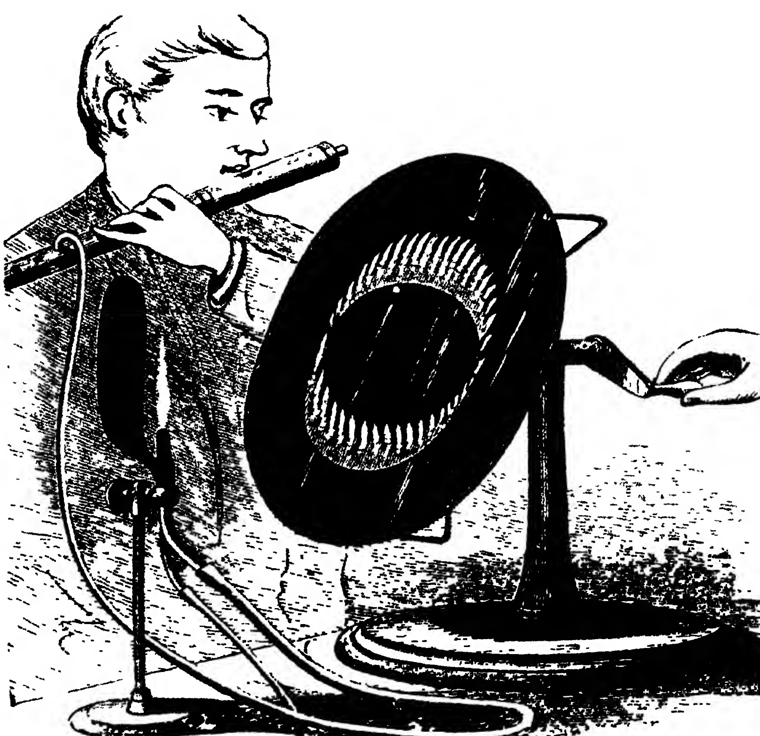
portion of the flame being more sensitive to disturbing influences than any other. This fact has been determined by experiments on sensitive flames, such as are described further on. By speaking in the mouthpiece while the gas is cut off from the burner, it is found that no sound proceeds from the burner, thus showing conclusively that the sounds are produced by the flame.

FIG. 139.



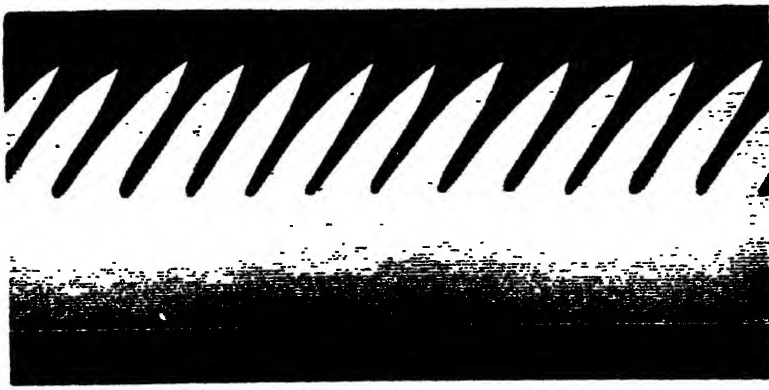
Vibrating Flame Apparatus.

FIG. 140.

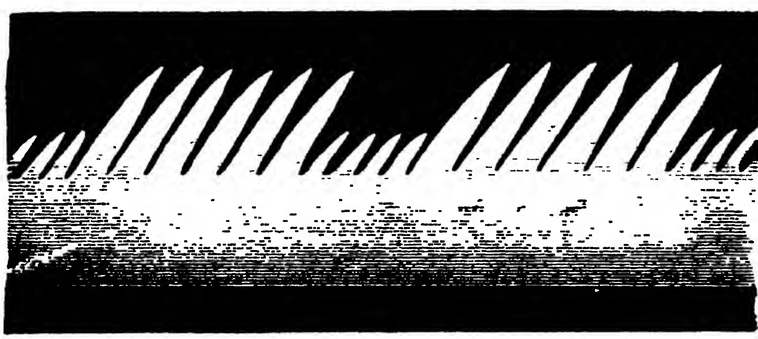


Circular Mirror.

FIGS. 141 TO 144.

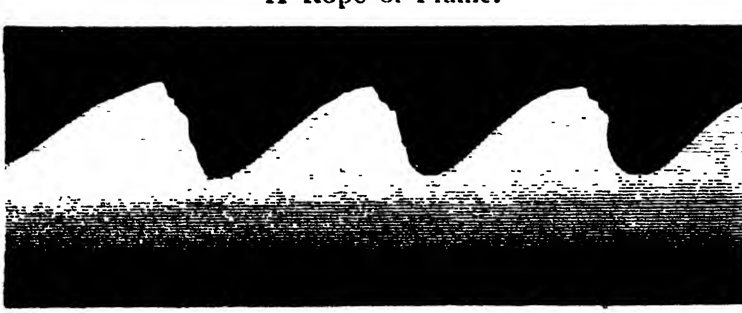


Manometric Flame.



A Trill.

A Rope of Flame.



Waves.

With a continuous speaking-tube explosive sounds are liable to extinguish the flame, but this difficulty may be avoided by cutting a longitudinal slit, an inch or so in length, in the speaking-tube near the mouthpiece.

When sounds are uttered in the mouthpiece with sufficient intensity to cause the flame to respond audibly, the sound waves induce longitudinal vibrations of the flame, which produce sounds varying in pitch and intensity with those uttered in the mouthpiece.

In Fig. 139 is shown a method of analyzing the vibrating flame. By means of a revolving mirror an image of each separate flame may be seen. In fact, the results are identical with those secured by Koenig's manometric capsule.

A circular mirror mounted obliquely on a spindle, as shown in Fig. 140, so that it will wabble, is effective in analyzing these flames. The image in this case has a crown-like appearance.

In the experiment here shown a flute is employed as the source of sound.

In Figs. 141, 142, 143, and 144 are illustrated some of the flame images seen in the revolving mirror.

COMPOSITION OF VIBRATIONS.

The optical method of studying sonorous vibrations has the advantage over other methods in being of interest not only to the student of acoustics, but also to those who care only for beautiful effects and have no regard for the lessons they teach.

As incidental to scientific work, the effect of beautiful experiments on the latter class may be worth a little consideration, as it not infrequently happens that the mere onlooker is lured into the paths of science by such means.

Among physical experiments, none are more attractive or instructive than those connected with the subject of sound. The experiments of M. Lissajous are particularly interesting, but when the figures are produced by the apparatus employed by Lissajous, a costly set of instruments will be required.

In the annexed engraving are shown two pieces of apparatus for producing these figures; that shown in Fig. 145 being quite inexpensive, that shown in Fig. 146 being a little

Fig. 145.

Simple Apparatus for Producing Lissajous' Figures.

more costly, and, at the same time, more efficient in its performance.

The device shown in Fig. 145 consists essentially of two plane mirrors, supported by torsional bands of rubber, one being supported so as to vibrate in a vertical

plane, the other in a horizontal plane, the mirrors being arranged with respect to each other so that the light received by one mirror will be reflected upon the face of the other mirror, by which it will in turn be projected through a double convex hand glass of long focus, to be finally received on the wall or screen.

The mirrors employed in the construction of this instrument are the small, inexpensive circular pocket mirrors sold on the street corners. They are about 1½ inches in diameter. To adapt them for use, a strip of tin, having its ends curled up to form hooks, is secured to the back of each mirror by means of sealing wax.

A baseboard provided with three standards supports the mirrors in the position of use. In one of the posts near the top are inserted two ordinary wire hooks, and near the bottom are inserted two similar hooks. Rubber bands received in these hooks are inserted in the hooked ends of the strip of tin attached to the back of the mirror. Several wire nails are driven into the face of the standard, for convenience in increasing or diminishing the tension of the rubber bands, the bands being drawn forward between the hooks and slipped over one or the other of the nails to increase the tension.

The mirror thus mounted on the vertical. rubber bands will, when struck lightly, vibrate in a horizontal plane. To change the rate of vibration, a weight is attached to the back of the mirror by means of beeswax. In the present case the weight consists of a piece of wire about 6 inches long. By varying the position of the wire on the mirror, *i. e.*, by placing it at different angles with the rubber bands that support the mirror, the rate of vibration may be greatly varied.

The second mirror is mounted in substantially the same way, the only difference being that the rubber bands are arranged horizontally, and supported by two posts instead of one. This mirror vibrates in a vertical plane, and its rate of vibration is changed in the manner above described. A candle or other source of light is arranged so that the light from it will fall on one mirror and be reflected to the other

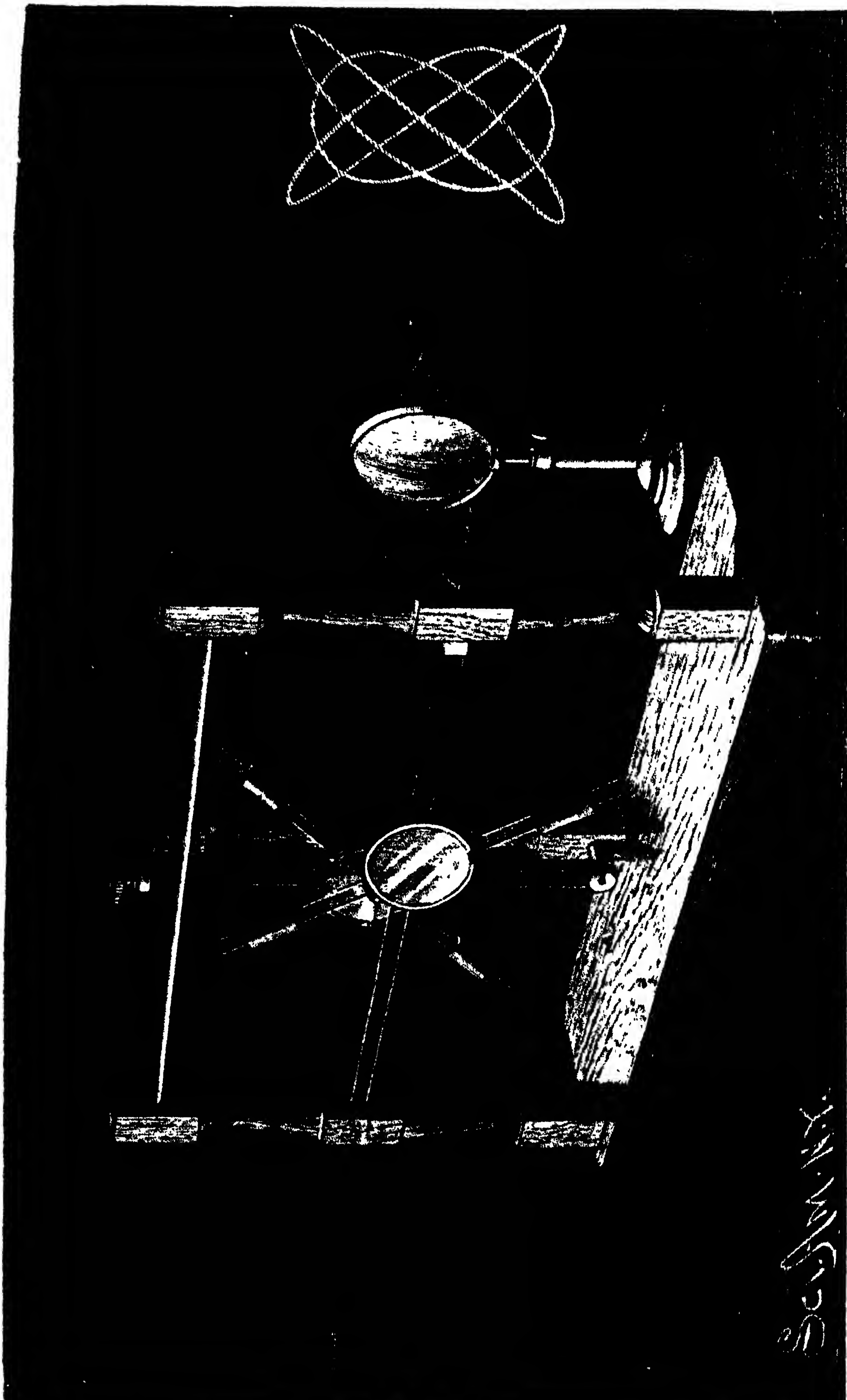
mirror, which in turn will project it through the lens to the wall. When the mirrors are set in vibration, a figure of more or less complicated character will be produced upon the wall. If the two mirrors vibrate in unison, a straight line, or an ellipse, or a circle will be produced. If one mirror vibrates twice as fast as the other, the figure will have the form of figure 8. The figures may be varied to an almost unlimited extent by changing the tension of the rubber bands, and by shifting the wire weights. As the various figures which may be produced are illustrated in most works on physics and on sound, it will be unnecessary to illustrate them here.

The apparatus shown in Fig. 146 will now be understood with little explanation, as the principle on which it operates is the same as that of the more simple form. The mirrors are each supported by two parallel steel wires, which are really but parts of the same wire. The extremities of the wire are securely fastened in the T-shaped head of a bolt, which in the case of the horizontal wires extends through one of the posts, and receives a milled nut, by which the tension of the wires may be varied.

The wire at its mid-length passes around a small sheave in the other post, so that as the wire is tightened the tension of its two branches will be equalized. The vertical wires are supported in the same way by studs projecting from the central post—the lower stud being provided with a sheave for receiving the wire, the upper stud being mortised for receiving the tension screw.

The mirrors are attached by small clamps which embrace both wires, and the arms supporting the adjustable weights are pivoted to the clamps. The weights may be swung in the plane of the mirror, and they are made adjustable on their supporting arms.

The best illumination aside from sunlight is that of a small parallel beam from an oxyhydrogen or electric lantern. The apparatus may be coarsely adjusted by turning the weighted arms on their pivots, and a finer adjustment may be secured by increasing or diminishing the tension of the wires.



Apparatus for Compounding Rectangular Vibrations.

RE-ENFORCEMENT OF SOUND.

The re-enforcement of sounds by the vibration of confined masses of air may be readily investigated without apparatus, that is, such apparatus as is commonly employed in acoustical experiments. A very simple experiment illustrating the fact that a sound may be strengthened by a confined body of air is illustrated in Fig. 147. The only

FIG. 147

Re-enforcement of Vocal Sounds.

requisite for this experiment is a paper tube 16 or 18 inches long and about 3 inches in diameter, or, in the absence of such a tube, a sheet of thick paper rolled into a tube will answer. This tube should be held with one end near the mouth, the opposite end being closed by the palm of the hand. By making a sound continuously with the voice, gradually rising in pitch, for example by singing O, with

the voice rising from the lowest note it is capable of making, toward the highest note, a point will be found where the sound is largely increased. This increase of sound will occur at the same point in the scale each time the experiment is tried with the same tube, thus showing that the dimensions of the tube are in some way related to the re-enforced note, and to that only. It will also be noticed that the vibrations of the air in the resonant tube not only affect

Fig. 148

Selective Power of a Resonant Vessel.

the auditory apparatus, but also have sufficient power to be plainly perceptible to the sense of touch, the vibrations being felt by the hand.

Another very simple experiment showing the same phenomenon in a different way is illustrated in Fig. 148. In this case the resonant vessel consists of a vase. Any vessel of substantially the same form may be used. The size is not very material, but by making several trials of different vessels a particular one will be found which will yield better results

than others on account of being of the correct dimensions. The experiment consists in holding the vase obliquely in close proximity to the ear, then running the chromatic scale upon any instrument having sufficient range, preferably upon a piano or organ. Some note of the scale will sound much louder than any of the others. By tilting the vase slightly in one direction or the other, so as to cause the ear to partly close the mouth of the vase, the resonant qualities may possibly be improved, as the movement of the vase in this manner amounts to tuning the resonator.

In Fig. 149 is represented an experiment in which the mouth is employed as a resonator, and an ordinary tea bell as the source of the sound. The tuning is effected by moving the tongue back and forth, also by opening or closing the lips. By a few trials a position of the mouth will be found which will cause it to respond to the sound of the bell and act as an efficient resonator.

The familiar instrument shown in Fig. 150 is used in connection with the mouth as a resonator. In this example the reed of the Jew's harp is made to yield a variety of tones, dependent upon the adjustment of the mouth and the force of the breath. The fundamental note of the reed is the clearest and best, and always distinctly heard. The forced overtones are less satisfactory, but suffice for playing tunes that are recognizable.

The experiment with the bell, represented in Fig. 151, is very striking, and is easily performed. The bell is simply an old fashioned clock bell or gong fastened on the end of a small wooden handle by a common wood screw. The resonator is a paper tube of about two-thirds the diameter of the bell, provided with a movable portion or diaphragm, as shown at A. Although the bell may be set in vibration by rapping it with the knuckles or striking it with a large sized rubber eraser, it may be more satisfactorily sounded by drawing a well resined bow over its edge. The bell is held over the mouth of the paper tube, and the diaphragm is moved up or down in the tube until a position is reached in which the bell will yield a full tone, which is much louder than it is capable of giving when used without the resona-

tor. The diaphragm is then fastened by means of sealing wax or glue.

To re-enforce one of the overtones of the bell, the opposite end of the tube is gradually shortened by paring off narrow strips from its edge until it responds to the high tone which the bell is capable of giving out when bowed in a particular way. Now, by causing the bell to vibrate strongly and placing it near opposite ends of the resonator in alternation, it will be found that the deeper cavity will

FIG. 149.

The Mouth used as a Resonator.

FIG. 150.

Experiment with the Jew's Harp

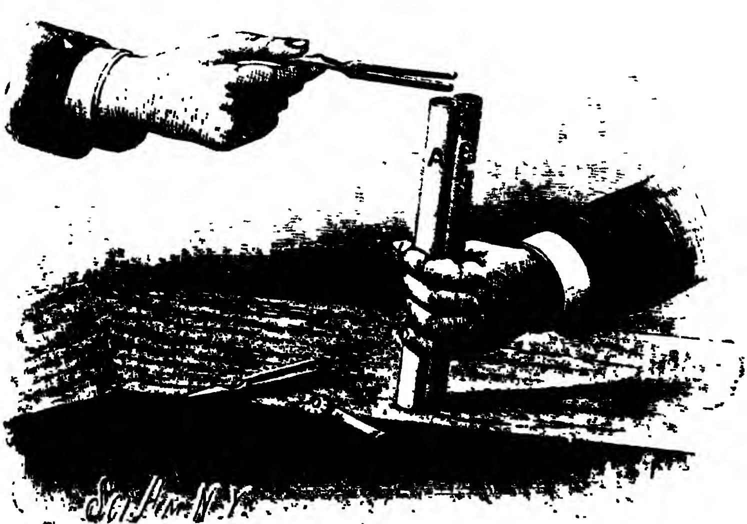
respond only to the grave note of the bell, while the shallower cavity will re-enforce only the overtone to which it is tuned. In this experiment it will be found a little more convenient to have separate resonators for the different tones.

In Fig. 152 is shown an experiment which is substantially the same as that just described in connection with the bell. In this case two tuning forks, A and C, are used as sound producers, and to each fork is adapted a resonator

FIG. 151.

Bell and Resonator.

FIG. 152.



Tuning Forks and Resonant Tubes.

consisting of a paper tube about ¾ inch in diameter and 8 or 10 inches long. Each tube is tuned to the fork in connection with which it is to be used by inserting a cork and moving it until the length of the inclosed air column is such as to respond to the fork. It will be found that the A resonator will respond only to the A fork, and the C resonator will re-enforce only the sound of the C fork.

In all these cases the resonant tube or cavity corresponds in depth to about one-quarter of a wave length of the particular sound which it is adapted to re-enforce. The wave proceeding from the sounding body strikes the bottom of the resonant chamber and is reflected back in time to proceed with the other half of the wave moving in the opposite direction, greatly augmenting its volume.

The combination of two series of sound waves may be made to produce silence if the relation of the two series be such that the air condensations of one series coincide with the rarefactions of the other series. This may be demonstrated by holding a tuning fork over its appropriate resonator and turning it until the plane of vibration of the fork is at an angle of 45° with the axis of the resonating tube. By placing the fork in the same position relative to the ear, the same phenomenon may be observed without the resonator.

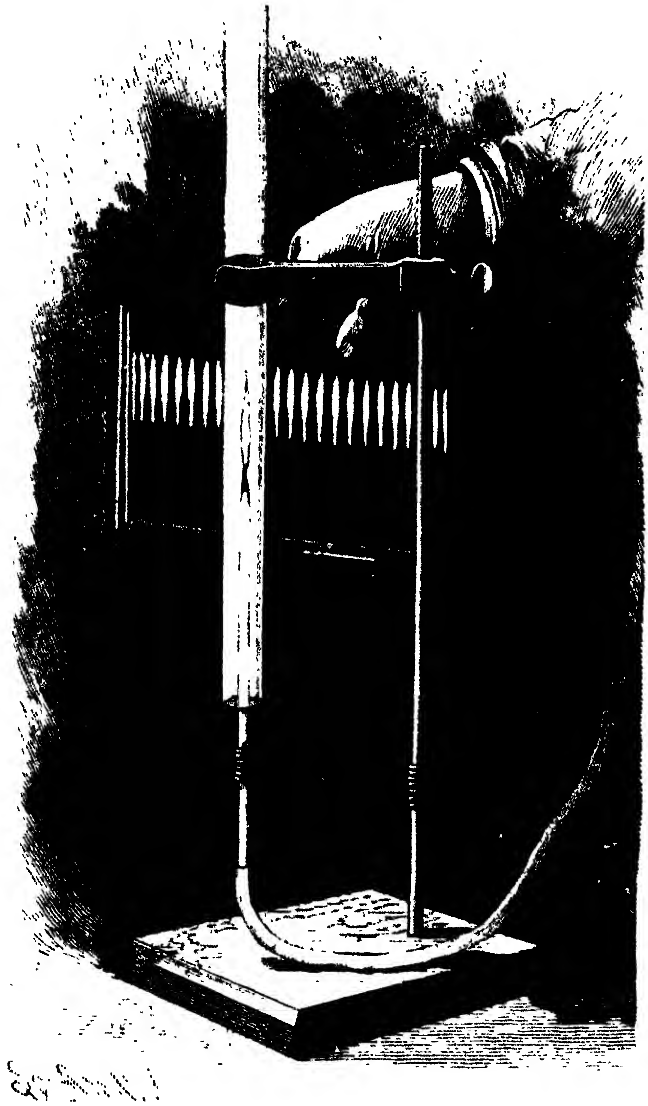
MUSICAL FLAMES.

The experiments of Tyndall and others on sounding flames are so interesting and so easily repeated with very simple appliances, that the student of physics, particularly in the department of acoustics, should not fail to repeat them. The production of musical sounds by means of flames inclosed in resonant tubes is especially easy. One form of this experiment is illustrated by Fig. 153.

For the mere production of sounds, a metal tube will answer, but for the analysis of the flame by which the sound is produced, a glass tube will be required. This tube, whether of metal or glass, may be 40 inches long and one inch internal diameter. It should be supported in a fixed vertical position in a suitable support, a filter support, for example. In a lower arm of the support is placed a glass

tube three-eighths inch in diameter, having its upper end drawn to a small circular aperture, which will allow sufficient gas to escape to form a pointed flame about 2½ inches

Fig. 153.



Production of Sounding Flames.

in height. The tube is drawn down by heating it near one end until it softens, by continually turning it in a gas flame, then quickly removing it from the flame, and drawing it out as far as possible. By making a nick with a fine file in one

side of the tube, at a point where it is about one-sixteenth inch in diameter, the tube may be broken squarely. It may then be tried as a burner. If the flame yielded by gas at full pressure is less than two inches in length, the tube should be again broken off at a point where it is a little larger in diameter, and if the opening happens to be too large, it may be reduced by holding the extreme end of the tube in a gas flame until it partly fuses, when it will contract.

The small glass tube is connected with the gas supply, and the jet is lighted and inserted centrally in the larger tube, and moved slowly upward in the tube until a clear musical note is heard. If the flame is full size, the note will be the fundamental note of the tube. By turning off the gas so as to make the flame three-fourths to one inch high, and again inserting the burner in the tube, a point will be found between its former position and the lower end of the tube at which a tone of higher pitch will be heard. This is one of the harmonics. If the burner with the small flame be carried further upward into the tube, a point will be reached where both the fundamental and harmonic will be produced simultaneously. These tones are produced by rapidly recurring vibrations of the flame, which are rendered uniform by the vibratory period of the column of air contained in the tube.

There are two methods of analyzing these flames. One consists in simply shaking the head, or quickly rolling the eyes from side to side, thereby enabling the eye to receive the impressions of the successive flames in different positions on the retina. The other consists in viewing the image of the flame in a revolving or oscillating mirror. By holding a looking glass in the hand, opposite the flame, as shown in the engraving, and oscillating the glass, what appears to be a single flame in the tube will be shown in the mirror as a succession of flames of like form connected at their bases.

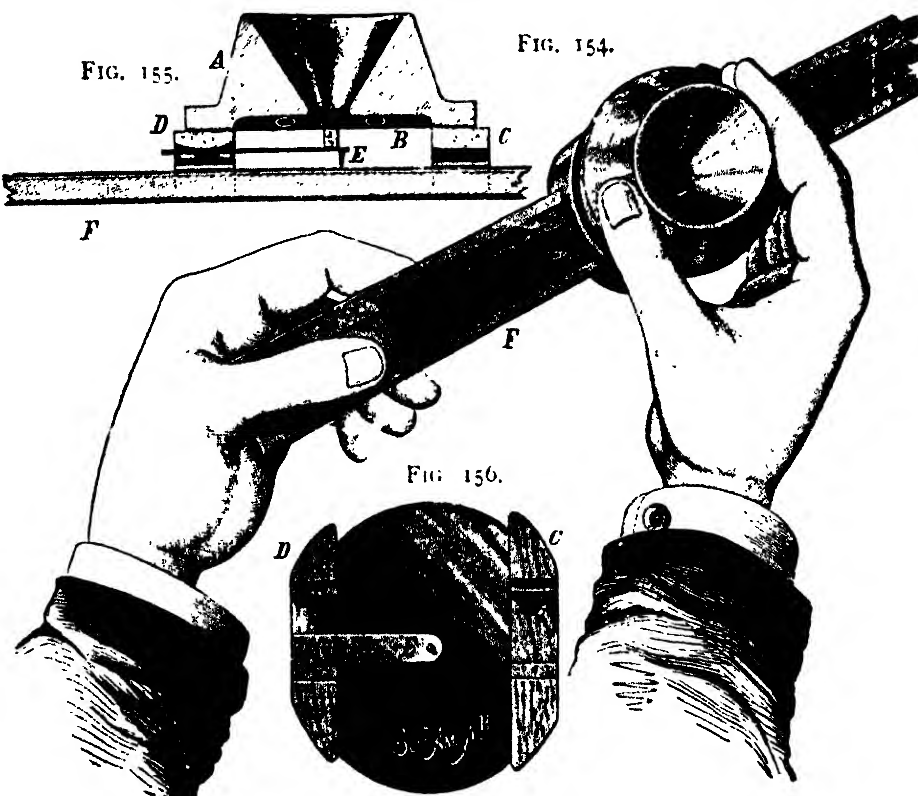
Another way of showing the periodic character of the flame consists in revolving a disk having alternating radial bands of black and white, in proximity to the tube, so that the disk is illuminated only by the light of the intermittent flame. When the disk attains a proper speed, the

intermittent illumination will cause it to appear stationary. This beautiful experiment is due to Toepler.

By employing a concave mirror instead of a plane one as described above, the image of the flame may be projected upon a screen.

A SIMPLE PHONOGRAPH.

This instrument, which is shown in perspective in Fig. 154, in section in Fig. 155, and in plan in Fig. 156, has



A Simple Phonograph.

a mouthpiece, A, to which is attached a thin ferrotype plate diaphragm, B, by means of a good quality of sealing wax or cement.

Upon the outer face of the diaphragm, and at opposite edges, there are guides, C D, for receiving the wooden strip, F. These guides present only a slight bearing surface to

the strip. The guide, D, is rounded to receive the spring, E, which is secured to it by two screws, by which also the spring is adjusted so as to bear with more or less force on the small rubber block which rests upon the center of the diaphragm.

A needle, which is sharpened like a leather sewing needle or awl, is soldered to the spring, and is located directly opposite the center of the diaphragm. The guides, C D, are placed so that the median line of the strip, F, is at one side of the needle. This strip has four slight longitudinal grooves, two on each side, which are made with an ordinary carpenter's gauge. These grooves are located so that when the strip is moved through the guides, one or the other of them will pass over the needle. A piece of beeswax is rubbed over the sides of the strip to give it an adhesive coating for receiving the foil used in recording the sounds.

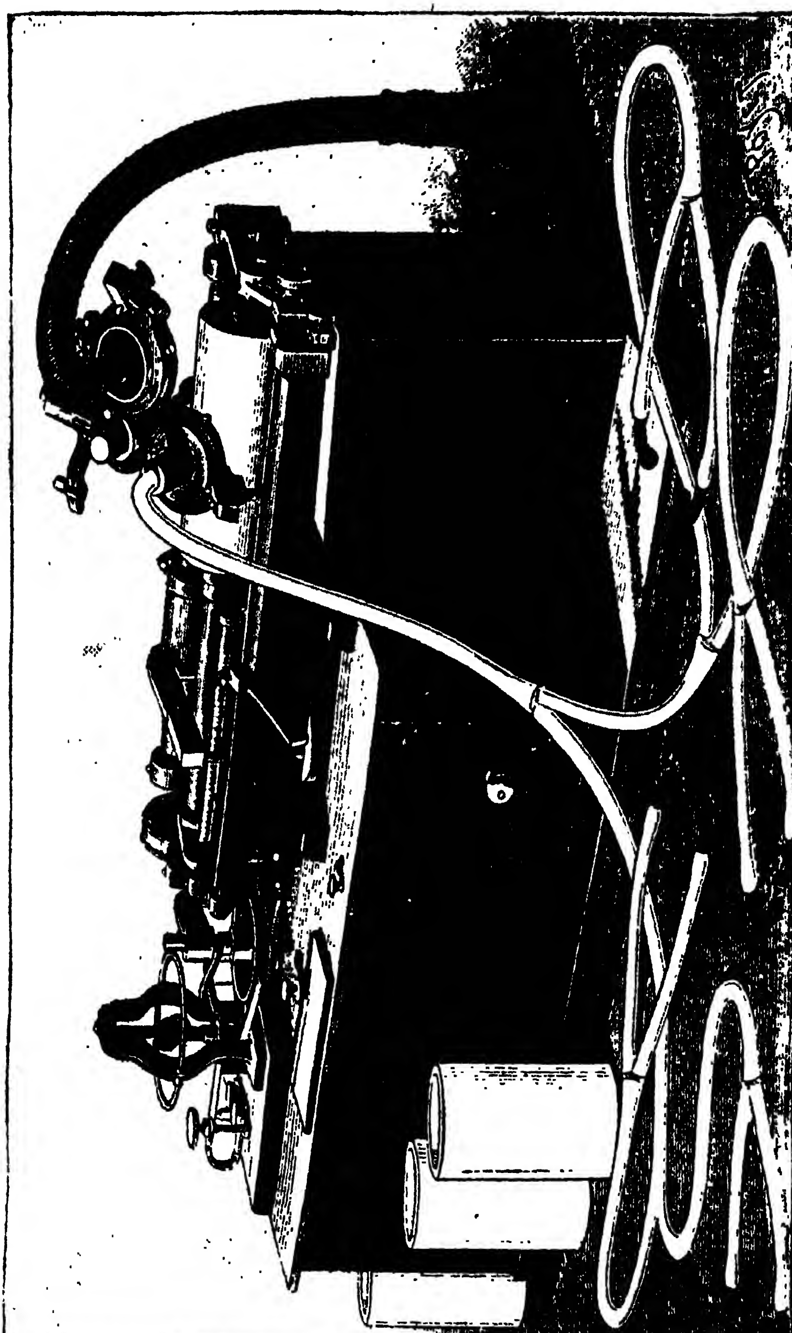
The foil, which should be rather heavy, must be cut into strips wide enough to extend beyond the grooves in the wooden strip. The foil is laid on the wooden strip and burnished down with the thumb nail, so that it will adhere. The strip thus prepared is placed in the guides, C D, and the needle is adjusted so that it indents the foil slightly as the stick is moved along.

By talking in the mouthpiece, and at the same time moving the strip along with a smooth, steady motion, the sounds are recorded on the foil. By passing the strip again through the guides, so that the needle traverses the same groove, and applying to the mouthpiece a paper funnel or resonator, the sounds or words spoken into the instrument will be reproduced. It is even possible to record the sounds on a plain strip of wood so that they may be reproduced. The engraving is about two-thirds the actual size of the instrument.

THE PERFECTED PHONOGRAPH.

Ten years ago a young man went into the office of the *Scientific American*, and placed before the editors a small, simple machine about which very few preliminary

FIG



Edison's New Phonograph.

remarks were offered. The visitor without any ceremony whatever turned the crank, and to the astonishment of all present the machine said: "Good morning. How do you do? How do you like the phonograph?" The machine thus spoke for itself, and made known the fact that it was the phonograph, an instrument about which much was said and written, although little was known.

It was the latest invention of Edison, and the editors and employes of the *Scientific American* formed the first public audience to which it addressed itself. The young man was Mr. Thomas A. Edison, even then a well known and successful inventor. The invention was novel, original, and apparently destined to find immediate application to hundreds of uses. Every one wanted to hear the wonderful talking machine, and at once a modified form of the original phonograph was brought out and shown everywhere, amusing thousands upon thousands; but it did not by any means fulfill the requirements of the inventor. It was scarcely more than a scientific curiosity or an amusing toy. Edison, however, recognized the fact that it contained the elements of a successful talking machine, and thoroughly believed it was destined to become far more useful than curious or amusing. He contended that it would be a faithful stenographer, reproducing not only the words of the speaker, but the quality and inflections of his voice; and that letters instead of being written would be talked. He believed that the words of great statesmen and divines would be handed down to future generations; that the voices of the world's prima donnas would be stored and preserved, so that, long after their decease, their songs could be heard. These and many other things were expected of the phonograph. It was, however, doomed to a period of silence. It remained a toy and nothing more for years. Finally it was made known to the public that the ideal phonograph had been constructed; that it was unmistakably a good talker; and that the machine, which most people believed to have reached its growth, had after all been refined and improved until it was capable of faithfully reproducing every word, syllable, vowel, consonant, aspirate and sounds of every kind.

During the dormancy of the phonograph, its inventor secured both world-wide fame and a colossal fortune by means of his electric light and other well known inventions. He has devoted much time to the phonograph, and has not only perfected the instrument itself, but has established a large factory provided with special tools for its manufacture, in which phonographs are to be turned out in great numbers.

The original instrument consists of three principal parts —the mouthpiece, into which speech is uttered; the spirally grooved cylinder, carrying a sheet of tin foil which receives the record of the movements of the diaphragm in the mouthpiece; and a second mouthpiece, by which the speech recorded on the cylinder is reproduced. In this instrument the shaft of the cylinder is provided with a thread of the same pitch as the spiral on the surface of the cylinder, so that the needle of the receiving mouthpiece is enabled to traverse the surface of the tin foil opposite the groove of the cylinder. By careful adjustment this instrument was made to reproduce familiar words and sentences, so that they would be recognized and understood by the listener; but in general, in the early phonographs, it was necessary that the listener should hear the sounds uttered into the receiving mouthpiece of the phonograph to positively understand the words uttered by the instrument.

In the later instruments, such as were exhibited throughout the country and the world, the same difficulty obtained, and perfection of articulation was sacrificed to volume of sound. This was necessary, as the instruments were exhibited before large audiences, where, it goes without saying, the instrument to be entertaining had to be heard. These instruments had each but one mouthpiece and one diaphragm, which answered the double purpose of receiving the sound and of giving it out again. Strangely enough, the recently improved phonograph is more like the original one than any of the others. It is provided with two mouthpieces, one for receiving and one for reproducing.

The new phonograph, which is shown in Fig. 157, is of about the size of an ordinary sewing machine. In its con-

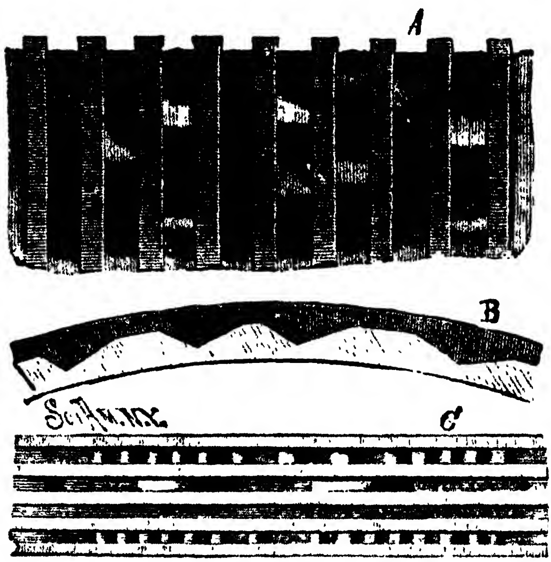
Edison Listening to the first Phonogram sent from England.

struction, it is something like a very small engine lathe; the main spindle is threaded between its bearings, and is prolonged at one end to receive the hardened wax cylinder upon which the sound record is made. Behind the spindle and the cylinder is a rod upon which is arranged a slide, having at one end an arm adapted to engage the screw of the spindle, and at the opposite end an arm carrying a pivoted head, provided with two diaphragms, whose positions may be instantly interchanged when desirable. One of these diaphragms is turned into the position of use when it is desired to talk to the phonograph, and when the speech is to be reproduced, the other diaphragm takes its place. The glass diaphragm, which receives the speech and makes the impressions upon the cylinder, is shown in Fig. 159. The needle by which the impressions are made in the wax is attached to the center of the diaphragm, and pivotally connected to a spring arm attached to the side of the diaphragm cell. The device by which the speech is reproduced is shown in section in Fig. 160. The cell contains a delicate glass diaphragm, to the center of which is secured a stud connected with a small curved steel wire, one end of which is attached to the diaphragm cell. The spindle of the phonograph is rotated regularly by an electric motor in the base of the machine, which is driven by a current from one or two cells of battery. The motor is provided with a sensitive governor which causes it to maintain a very uniform speed. The arm which carries the diaphragms is provided with a turning tool for smoothing the wax cylinder preparatory to receiving the sound record.

The first operation in the use of the machine is to bring the turning tool into action and cause it to traverse the cylinder. The turning tool is then thrown out, the carriage bearing the diaphragms is returned to the position of starting, the receiving diaphragm is placed in the position of use, and as the wax cylinder revolves, the diaphragm is vibrated by the sound waves, thus moving the needle so as to cause it to cut into the wax cylinder and produce indentations which correspond to the movements of the diaphragm. After the record is made, the carriage is again

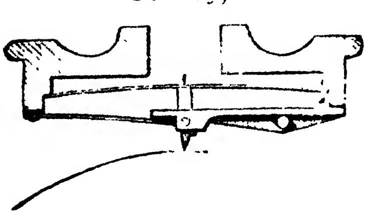
returned to the point of starting, the receiving diaphragm is replaced by the reproducing diaphragm, and the carriage is again moved forward by the screw, as the cylinder revolves, causing the point of the reproducing diaphragm to traverse the path made by the recording needle. As the point of the curved wire attached to the diaphragm follows

Fig. 161.



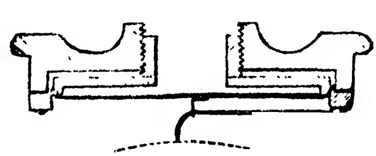
Phonographic Record Magnified.

Fig. 159.



Receiving Diaphragm.

Fig. 160.



Speaking Diaphragm

the indentations of the wax cylinder, the reproducing diaphragm is made to vibrate in a manner similar to that of the receiving diaphragm, thereby faithfully reproducing the sounds uttered into the receiving mouthpiece.

A crucial test of the capabilities of this machine was recently made in our presence, at Edison's laboratory, near

Llewellyn Park, Orange, N. J. A paragraph from the morning newspaper was read to the machine in our absence, and when upon our return to the instrument it was reproduced phonographically, every word was distinctly understood, although the names, localities, and the circumstances mentioned in the article were entirely new and strange to us. Another test of the perfection of the machine was the perfect reproduction of whistling and whispering, all the imperfections of tone, the half tones and modulations even, being faithfully reproduced. The perfect performance of the new instrument depends upon its mechanical perfection—upon the regularity of its speed, the susceptibility of the wax cylinder to the impressions of the needle, and to the delicacy of the speaking diaphragm. No attempt is made in this instrument to secure loud speaking—distinct articulation and perfect intonation have been the principal ends sought.

A highly magnified section of the phonograph cylinder, showing the indentations, is illustrated in Fig. 161; A representing a section of the face of the cylinder, B a transverse section of a portion of the cylindrical wax shell, and C showing a less magnified face view of a small portion of the cylinder.

The new phonograph is to be used for taking dictation for taking testimony in court, for reporting speeches, for the reproduction of vocal music, for teaching languages, for correspondence, for civil and military orders, for reading to the sick in hospitals, and for various other purposes too numerous to mention.

Imagine a lawyer dictating his brief to one of these little machines; he may talk as rapidly as he chooses, every word and syllable will be caught upon the delicate wax cylinder, and after his brief is complete he may transfer the wax cylinder to the phonograph of a copyist, who may listen to the words of the phonograph and write out the manuscript. The instrument may be stopped and started at pleasure, and if any portion of the speech is not understood by the transcriber, it may be repeated as often as necessary.

In a similar manner a compositor may set his type directly from the dictation of the machine, without the necessity of

"copy," as it is now known. Mr. Edison says that the whole of "Nicholas Nickleby" could be recorded upon four cylinders, each 4 inches in diameter and 8 inches long, so that one of these instruments in a private circle or in a hospital could be made to read a book to a number of persons. This is accomplished by means of a multiple earpiece.

The little wax cylinders upon which the record is made are provided with a rigid backing, and the cylinders are made in different lengths; the shortest—one inch long—having a capacity of 200 words, the next in size 400 words, and so on. These cylinders are very light, and a mailing case has been devised which will admit of mailing the cylinders as readily as letters are now mailed. The recipient of the cylinder will place it on his own phonograph and listen to the phonogram—in which he will not only get the sense of the words of the sender, but will recognize his expression, which will, of course, have much to do with the interpretation of the true meaning of the sender of the phonogram.

Fig. 158 is a life-like picture of Mr. Edison photographed while he listened to his first phonogram from abroad.

A very interesting and popular use of the phonograph will be the distribution of the songs of great singers, sermons and speeches, the words of great men and women, music of many parts, the voices of animals, etc., so that the owner of a phonograph may enjoy these things with little expense.

It may even be pressed into the detective service and used as an unimpeachable witness. It will have but one story to tell, and cross examination cannot confuse it.

REFLECTION AND CONCENTRATION OF SOUND.

The particular action of sound to be dealt with here is that of reflection, examples of which are presented in every echo; and whispering galleries are but the exhibition of the same thing, although more rare. A few of them have a world-wide reputation.

In his article on sound in the "Encyclopædia Metropolitana," Sir John Herschel mentions the abbey church of St.

Albans, where the tick of a watch may be heard from one end of the edifice to the other. In Gloucester Cathedral a gallery of octagonal form conveys a whisper 75 feet across the nave. In the whispering gallery of St. Paul's the faintest sound is conveyed from one side of the dome to the other, but is not heard at any intermediate point. The dome of the capitol at Washington is an excellent whispering gallery. These effects are due to an accidental arrangement of the walls.

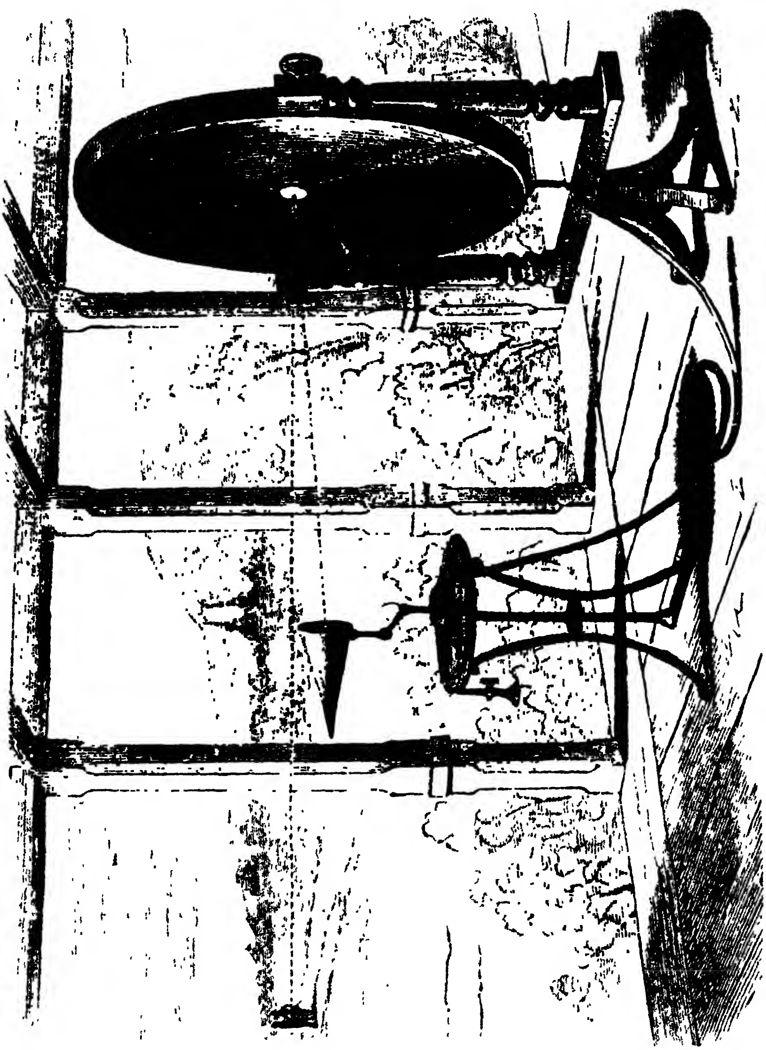
Sails of ships are sometimes inflated by the wind so that they act as concentrating reflectors of sound. Arnott says that in coasting off Brazil he heard the bells of San Salvador from a distance of 110 miles, by standing before the mainsail, which happened at the time to assume the form of a concave reflector, focusing at his ear.

Sounds may be received and reflected by means of metallic parabolic reflectors, so that many times the volume of sound that naturally strikes the ear will be concentrated, rendering sounds audible that might otherwise be too distant or too faint to be heard. Such reflectors of necessity have a fixed form, and are available under certain conditions only. The accompanying engraving (Fig. 162) represents a sound reflector that may be focused as readily and directed as easily as a telescope. It is, in fact, a portable and adjustable whispering gallery, having many useful applications.

The instrument is very simple, consisting essentially of an airtight drum, one head of which is rigid, the other elastic. This drum, or more properly reflector, is mounted on pivots in a swiveled support, and is provided with a flexible tube having a mouthpiece and stop cock at its free end. Two wires are stretched across the face of the reflector at right angles to each other, and support at their intersection a small plane mirror, the office of which is to determine the position of the reflector in relation to the direction of the sound. A small ear trumpet or funnel, which is shown on the table, is used in connection with the reflector, to increase its effect by gathering portions of the sound that might escape the unaided ear.

The reflector is adjusted by looking through the ear

trumpet toward the small plane mirror, and moving the sound reflector until the source of sound is seen in the mirror. The reflector is then focused by exhausting the air from behind the flexible head until the required degree of



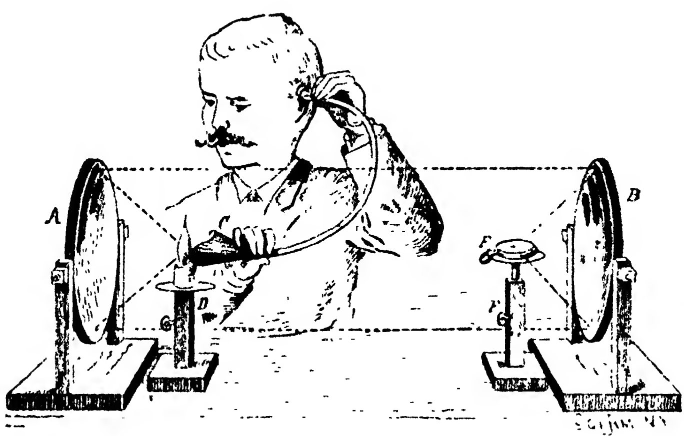
F 62.

Adjustable Sound Reflector.

concavity is reached, which will be when sounds are distinctly heard in the ear trumpet. The air is readily exhausted from the reflector by applying the mouth to the mouthpiece. The details of the construction of the apparatus are shown in the engraving.

Of course, the operation of the instrument may be reversed—that is, sounds made at the focus of the reflector may be projected in parallel lines over long distances, but in practice a speaking trumpet is found to be better for this purpose. The engraving shows but one of the applications of the reflector. It would be a simple matter to provide for a deaf person an instrument on this principle. It could hang on the walls of the parlor unnoticed, as it might take the form of a richly framed picture, and would concentrate a great volume of sound at a single point. The same device

FIG. 163.



Reflection of Light and Sound.

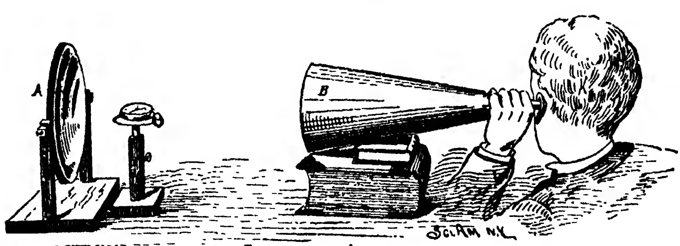
may also be applied to an auditorium to project the voice of the speaker in any required direction.

To concentrate and project light, heat, and sound by means of concave mirrors is generally supposed to necessitate the use of expensive parabolic mirrors, articles practically out of the reach of amateur experimenters, and not to be found in every institution of learning. To perform most of the experiments possible with concave mirrors, the spun metal reflectors used in large lamps answer exceedingly well. The projection of images and the accurate determination of the foci are the only experiments impossible with such reflectors. The largest size to be found ready made is 10 inches in diameter, with a principal focus of about 8 or 9

inches. The price is $1.50 per pair. To prepare them for use, two common wood screws are secured to them at diametrically opposite points, the heads of the screws being soldered to the edges of the mirrors, so that the screws project radially. Each mirror is provided with a stand formed of a base and two uprights. The wood screws project through the uprights, and are provided with wooden nuts.

To facilitate the experiments to be performed with the concave mirrors, two or three small stands are required. It is desirable that these stands be made adjustable. If nothing is at hand that will answer the purpose, a very good adjustable stand may be made by soldering a disk of tin to the head of a 4 inch wood screw, and inserting the screw in

Fig. 164.



Reflection and Concentration of Sound.

a short column, as shown in the engraving. A paper trumpet, 8 inches in diameter at the larger end and 2 feet in length, is useful, and a rubber tube having a small funnel at one end and an ear piece at the other end is necessary.

To show the concentrating power of one of these common reflectors, place it so that its concave surface faces the sun. Then place a piece of dark-colored cloth in the focus. It is at once ignited.

Place two reflectors, A B, 4 or 5 feet apart, with their concave surfaces facing each other, as shown in Fig. 163. Place a short candle on the stand, D, so as to reflect a parallel beam that will cover the reflector, B, as nearly as possible. Then place a watch, E, in the focus of the reflector, B, upon the stand, F. Now hold the funnel, C, with its mouth facing the reflector, A, and immediately behind the candle, or,

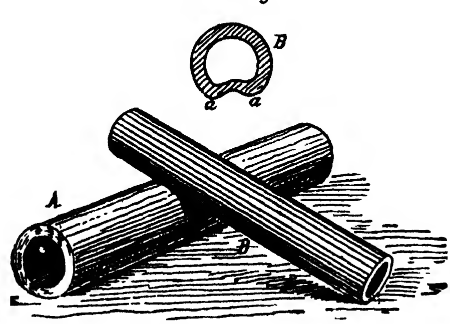
better, remove the candle and place the funnel in the position formerly occupied by the candle flame. With the funnel at this point the ticking of the watch will be distinctly heard, but a slight movement of the funnel in either direction will render the ticking inaudible. This experiment shows that the laws governing the reflection of light and sound are the same.

In Fig. 164 the use of the trumpet in connection with a concave reflector is illustrated. The reflector, A, is adjusted to the trumpet, B, by means of the light of a candle placed on the stand in the focus of the reflector. Afterward the candle is replaced by the watch. With this arrangement the watch may be heard twenty or thirty feet away.

TREVELYAN ROCKER.

This apparatus consists of a short piece, A, of lead pipe, about an inch in diameter, and a piece, B, of thick brass tubing, about ¾ inch outside diameter and five or six inches long. The lead pipe is flattened a little to keep it from rolling, and the surface along the side which is to be uppermost is scraped and smoothed. The brass tubing, B, is filed thin, upon one side, near one end, and the thin part is driven in with the pein of a hammer or a punch so as to leave the longitudinal ridges, *a a*, as shown in the end view in Fig. 165.

Fig. 165.



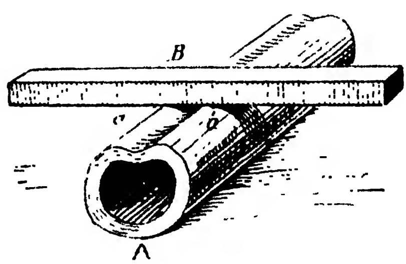
Trevelyan Rocker.

When the brass tube is heated and placed across the lead pipe, as shown in Fig. 165, with the ridges, *a a*, in

contact with the lead pipe, the brass tube begins to rock, invisibly, of course, but with sufficient energy to give forth a clear musical note. If it does not start of itself, a little jarring will set it going, and it will continue to give forth its sound for some time.

The accepted explanation of this phenomenon is that the contact of the hot brass with the lead causes the lead to suddenly expand and project a microscopic distance upward. These upward projections of the lead alternate between the

FIG. 166



Rocking Bar.

two points of contact, and thus cause the tube to rock with great rapidity and regularity.

In Fig. 166 is shown a modification of the experiment, in which the lead is indented to form the two contact surfaces, *a a*, and the heated bar, B, is made to rock at a comparatively slow rate, giving forth a grave note. By careful manipulation, the bar may be made to rock both longitudinally and laterally, thus giving forth a rhythmic combination of the two sounds.

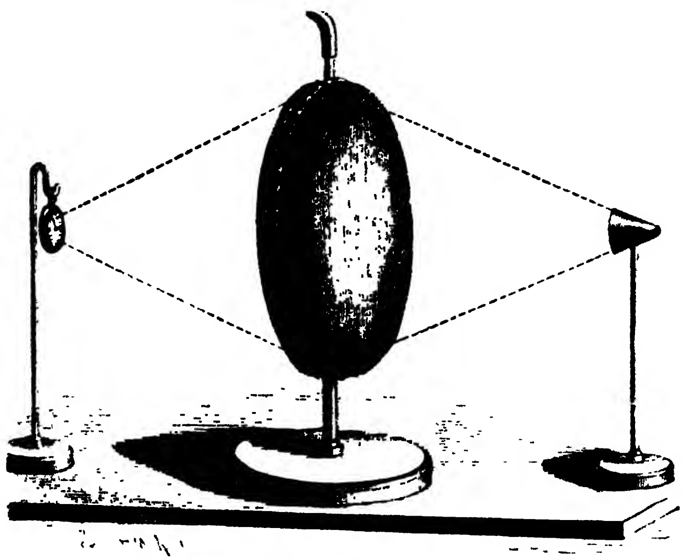
REFRACTION OF SOUND.

In Figs. 167 and 168 is illustrated an adjustable lens for showing *the refraction of sound.* The frame of the lens consists of three 12 inch rings of large wire, soldered together so as to form a single wide ring with two circumferential grooves. In the central part of the ring, at the bottom, is inserted a standard, and in the top is inserted a short metal tube. Over the edges of the ring are stretched disks of the thinnest elastic rubber, which are secured by a stout

thread wound around the edges of the rubber, clamping them in the grooves of the ring.

By inflating the lens through the tube with carbonic acid

FIG. 167.



Sound Lens.

gas, it may be focused as desired. A watch placed at the focus upon one side of the lens can be distinctly heard at the focal point on the opposite side of the lens, when it can be heard only faintly or not at all at points only slightly removed from the focus, thus showing that the sound of the ticking of the watch has been refracted by the lens in much the same manner as light is refracted by a glass lens.

FIG. 168

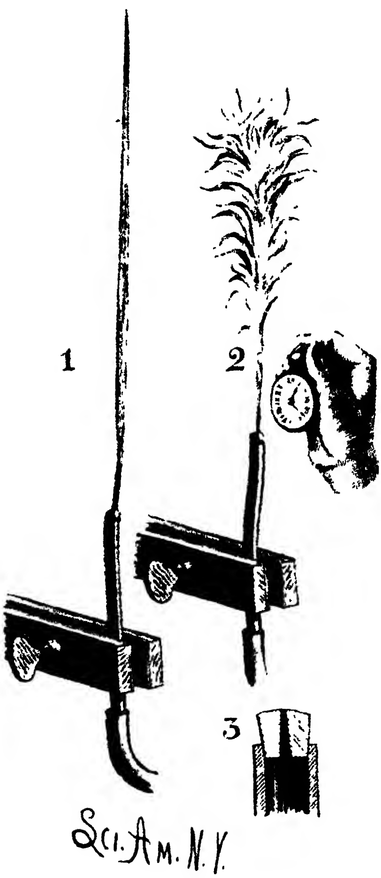
Section of Sound Lens.

SENSITIVE FLAMES.

The sensitive flame, first observed by Dr. Le Conte and afterward developed by Tyndall and Barrett, exhibits some of the curious effects of sound. For its production it is necessary that the gas be under a pressure equal to that of a column of water six or eight inches high. The common method

of securing the required pressure is to take the gas from a cylinder of compressed illuminating gas, such as is used for calcium lights. Another method is to take the gas from a weighted gas bag, and still another is to fill a sheet metal tank with gas and displace it with water in the manner illustrated in Fig. 170. The burner is shown at 1, 2, and 3, Fig. 169. It consists of a small tip inserted in the end of a suitable tube. The tip in the present case is made of brass, but those commonly used for this purpose are of steatite. They are superior to the metal ones, but require careful selection.

FIG. 169.



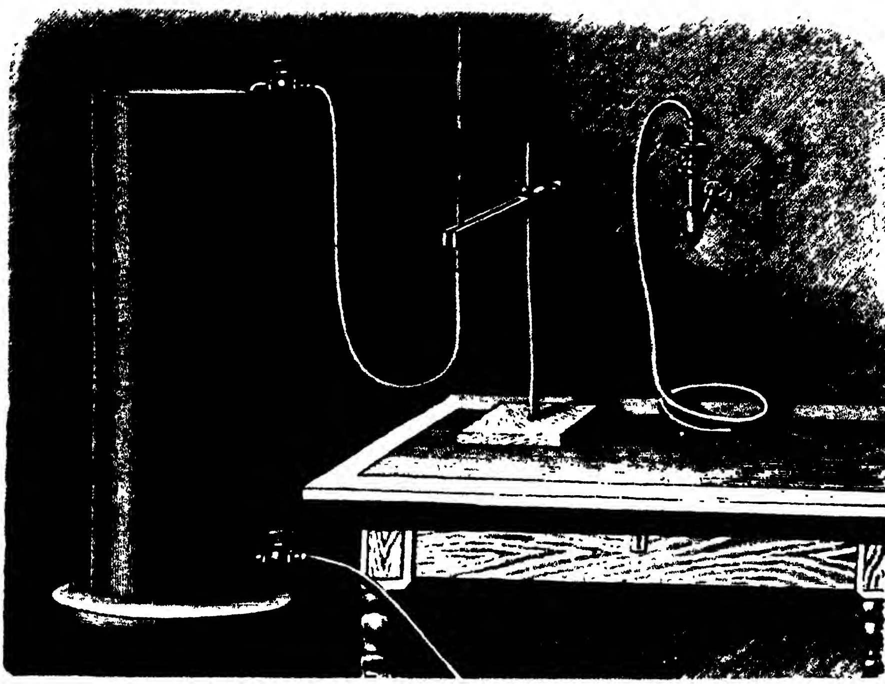
Burner for Sensitive Flame.

It has been found that some of the lava pinhole burner tips used in certain kinds of gas stoves answer admirably for this purpose, and cost very little. A tip with a round, smooth hole is to be selected. The bore of the tip is here shown tapering. Its smaller diameter is 0·035 inch The burner is supported in the manner shown at 1 and 2, or in any other convenient manner, and gas under a suitable pressure flows through and is ignited. The flame will be tall and slender, as shown at 1. By regulating the gas pressure carefully, an adjustment will be reached at which the flame will be on the verge of flaring. A very slight increase of pressure beyond this point will cause the flame to shorten and roar. When the flame is at the point of flaring, it is extremely sensitive to certain sounds, particularly those of high pitch. A shrill whistle or a hiss will cause it to flare. The rattle of a bunch of keys will produce the

same result. It will respond to every tick of a watch held near it.

Tyndall says that when the gas pressure is increased beyond a certain limit, vibrations are set up in the gas jet by the friction of the gas in the orifice of the burner. These vibrations cause the flame to quiver and shorten. When the flame burns steadily, any sound to which the gas jet will respond will throw it into sympathetic vibration. Experi-

FIG. 170.



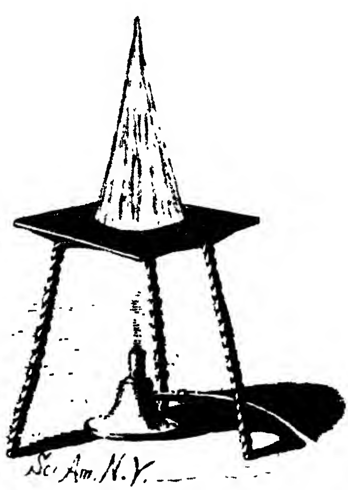
Apparatus for producing Gas Pressure for the Sensitive Flame

ment has demonstrated that the seat of sensitiveness of the flame is at the base of the flame, at the orifice of the burner.

The method of producing the required gas pressure illustrated in Fig. 170 is available when gas bags or cylinders of compressed gas are not to be had. A tin cylinder of about 15 gallons capacity is provided at the top and bottom with valves. The lower valve is connected with a hydrant, and the cylinder is filled with water, while the upper valve is left open to allow of the escape of air. When the cylin-

der is filled with water, the supply is shut off and a tube from a gas burner is connected with the upper valve and the gas is turned on. Then the water is allowed to escape from the cylinder, thereby drawing in the gas. When the cylinder is filled with gas, the valves are closed and the lower one is again connected with the hydrant, while the upper one is connected with the pinhole burner. The valves on the cylinder are again opened and water is admitted at the rate required to produce the desired gas pressure. Only two precautions are necessary in this experiment; one is to avoid a mixture of air and gas in the cylinder by driving out all the air, the other is to avoid the straining of the cylinder by water pressure.

FIG. 171.

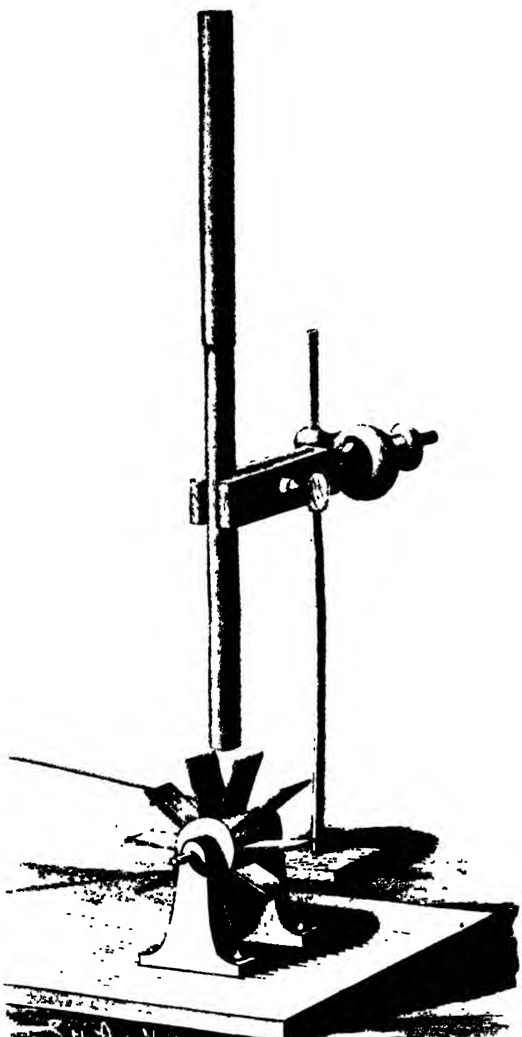


Sensitive Flame with Gas at Ordinary Pressure.

Another sensitive flame, which has several advantages over the one described, is shown in Fig. 171. It requires no extra gas pressure, and it is more readily controlled than the tall jet. It was discovered by Mr. Philip Barry, and the discoverer's letter to Mr. Tyndall concerning it is found in Tyndall's work on sound. In the production of this flame a pinhole burner, like that already described, is employed. Two inches above the burner is supported a piece of 32-mesh wire gauze, about 6 inches square. The gas is turned on and lit above the wire gauze. It burns in a conical flame, which is yellow at the top and blue at the base. When the gas pressure is strong, the flame roars continuously. When the gas is turned off, so as to stop the roaring altogether, the flame burns steadily and exhibits no more sensitiveness than an ordinary flame. By turning on the gas slowly and steadily, a critical point will be reached at which any hissing noise will cause it to roar and become non-luminous. Any degree of sensitiveness may be attained by careful adjust-

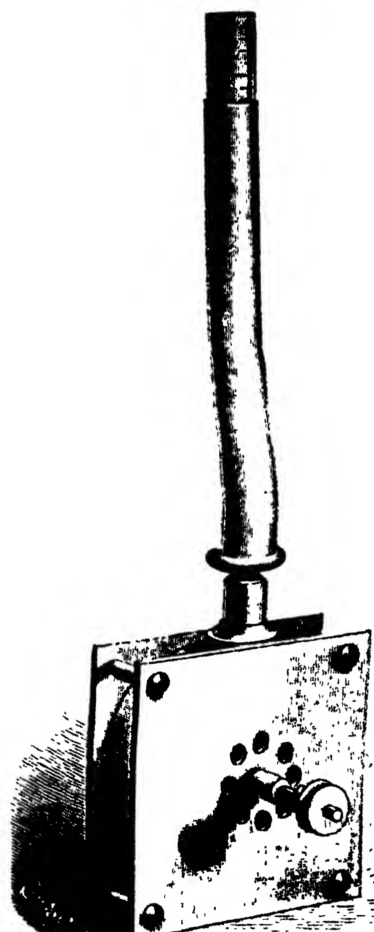
ment of the gas supply. A quiet room is required for this experiment. The rustle of clothes, the ticking of a clock, a whisper, a snap of the finger, the dropping of a pencil, or in

FIG. 172.



Determining Speed by Resonance.

FIG. 173.



Siren for Measuring Velocities.

fact almost any noise, will cause it to drop, become non-luminous, and roar. It dances perfect time to a tune whistled *staccato* and not too rapidly.

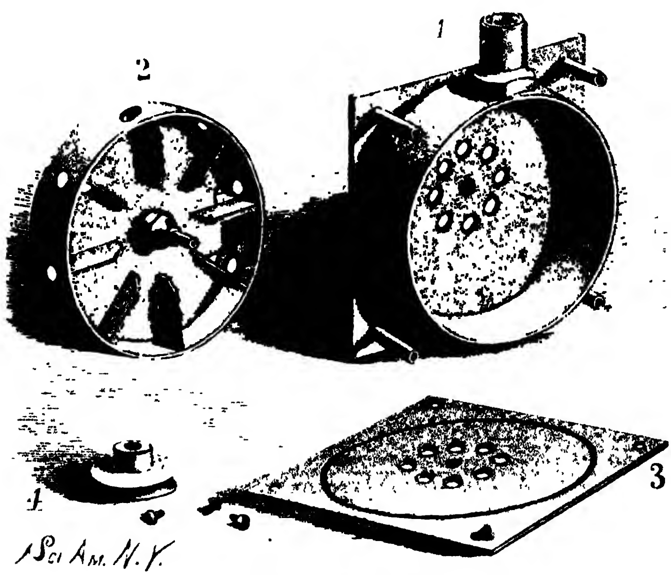
The flame at its base presents a large surface to the air,

so that any disturbance of the air sets the flame in active vibration.

A SIREN FOR MEASURING VELOCITIES.

In this instrument advantage is taken of the well known fact that for every tone a resonator may be provided that will respond to and re-enforce the vibrations producing that tone. The length of a closed resonant tube is one-fourth that of the sound wave to which it responds. The length of an open resonant tube is one-half that of the sound wave to which it responds. It is obvious that a telescopic tube

FIG. 174.



Details of the Siren.

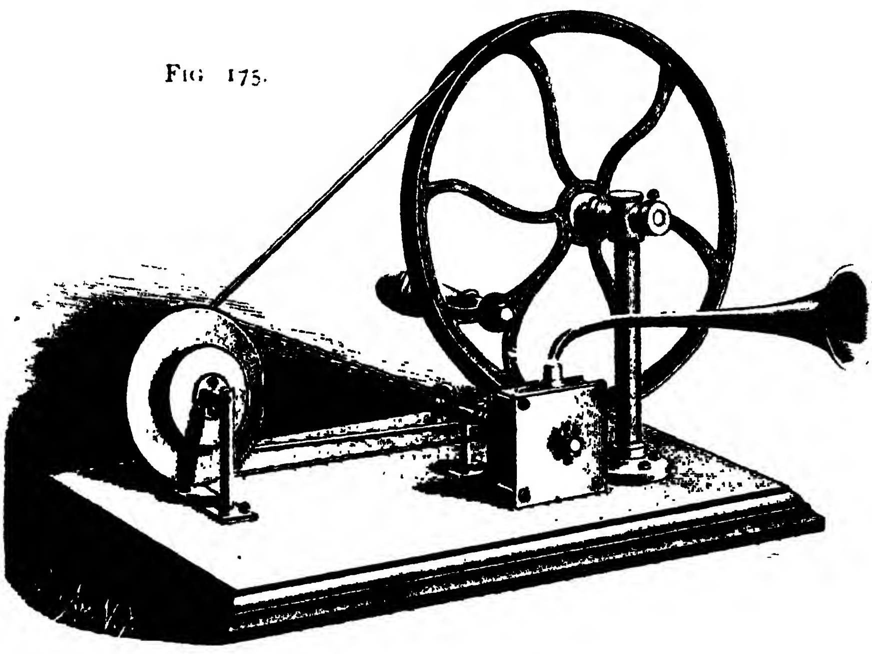
may be adjusted to respond to different pitches. Knowing the number of vibrations required per second to produce a certain pitch, it is comparatively an easy matter to determine the rate of any series of regular air vibrations by adjusting the tube to such a length as to cause it to respond to the vibrations.

In Fig. 172 is shown a resonant tube supported over a small fan wheel. The fan has ten blades, so that during one revolution it sends ten puffs of air up the tube. By gradually increasing the velocity of the fan a speed will be reached

at which the tube yields a low but distinct musical tone. If, for example, this tone corresponds to middle *c*, it is known that 261 puffs of air are made in the tube, and that since there are ten blades to the fans, the number of revolutions of the fan shaft must be $261 \div 10 = 26{\cdot}1$ per second, or 1,566 revolutions per minute.

In Fig. 173 is illustrated a siren constructed on this principle. The parts of this instrument are shown in detail in Fig. 174. It consists of a circular casing containing a rotary fan which draws in air at the center and discharges it

FIG. 175.



Centrifugal Siren.

through an opening in the top of the casing. The blades of the fan are arranged radially upon opposite sides of the disk, and the fan is encircled by a perforated rim, which fits the circular casing and acts as a valve in controlling the escape of air. The perforations of the rim correspond in number and position with the fan blades.

The discharge opening of the casing is provided with a socket for receiving a resonator. The resonator shown

in Fig. 173 consists of a pair of tubes made to slide telescopically one within the other, the inner one being graduated to indicate the different lengths required for different pitches, and consequently for different speeds. As the fan revolves, the air drawn in through the holes at the center of the casing is thrown outward by centrifugal force, thus maintaining a pressure of air at the periphery of the fan. The holes in the rim of the fan allow the air to escape in regular puffs, the frequency of which depends upon the velocity of the fan. These puffs produce sounds varying in pitch and intensity with the speed of the fan, and the resonating tube re-enforces the particular note to which it is tuned, so that when a speed is reached corresponding with the adjustment of the tube, the fact is known by the superior strength of that particular note. Any change of speed may be detected by the lessening of the intensity of the sound and the change of pitch.

The siren is shown in Fig. 175 in connection with mechanism for driving it by hand. It is provided with a revolution counter and with a trumpet-shaped resonator. It is designed to be used in the same manner as the siren of Cagniard Latour, and, like that instrument, it yields sounds under water

CHAPTER IX.

EXPERIMENTS WITH THE SCIENTIFIC TOP.

Several experiments possessing more or less interest are illustrated in Plate III. This chapter is introduced at this

PLATE III.

Experiments with the Scientific Top.

point on account of the relation of its subject matter to the preceding and succeeding chapters.

The ability of the heavy top to run for a long time and

maintain an equable motion renders it particularly serviceable in experiments requiring uniformity of action.

Two experiments in sound are illustrated: 1, Plate III, showing the adaptation of a simple siren to the top, and 2, Plate III, Savart's wheel. The siren consists of a disk of pasteboard, having four eccentric rows of 3-8 inch holes, there being 12 holes in the inner row, 15 in the next, 18 in the next, and 24 in the outer row. The disk is varnished with shellac to render it waterproof. It is mounted on a chuck fitted to the tapering hole of the top spindle. When the disk is rapidly rotated by the top, and a jet of air is blown upon either row of holes through a flexible tube provided with a small glass or metallic nozzle, a musical sound will be produced by the air pulsations caused by the interruptions of the air jet by the perforated disk. The sounds produced by the different rows of holes are those of the perfect major chord. By holding a card so that its corner will touch the perforated disk at any row of holes, it will be found that the taps of the card will produce the same tones as the puffs of air from the tube. Savart's wheel is simply a toothed disk fitted to the chuck and adapted to be rotated by the top. When the disk is turned very slowly, with the edge of a card held against the teeth, a series of little taps are heard, which do not at all resemble a musical sound; but when the wheel is revolved rapidly by the top, the contact of the card with its periphery produces a sound that may fairly be called musical, the sound being composed of the rapidly repeated taps.

At 3, Plate III, is shown a disk similar to that used for the siren, but having double the number of holes in each circular row. The holes are 1-8 inch in diameter. The disk is blackened to render the effects more conspicuous, and the hole in the center of the disk is eyleted to prevent wear. A metal disk, secured to a tapering spindle fitted into the top spindle, carries a crank-pin 3-16 inch from the axis of rotation. The eyelet of the disk is placed loosely on this crank pin, and when the crank is revolved by the top the disk is gyrated; every part of its surface being made to travel in a circular path 3-8 inch in diameter, when sufficient friction is

applied to it to prevent it from rotating with the top. In this case each perforation of the disk forms a circle, and the circles formed by the entire series of holes interlace, appearing like so many chain links interlocked. By allowing the disk to revolve at different speeds very complicated figures are produced, sometimes like lacework, sometimes like twisted chainwork. Occasionally one part of the figure will appear to turn in one direction while another part turns in the opposite direction. Some of these figures are shown at 4 and 5, Plate III. A similar experiment, developed in a different way, is shown at 7. The black cardboard disk is provided with a central eyelet, which receives the crank pin, as in the case of the perforated disk. On each of two diametrical lines crossing each other at right angles are formed pairs of holes, in which are cemented silvered glass beads or bright spherical steel buttons. The latter were used on the disk illustrated. They are symmetrically arranged, so that the inner four may follow each other in the same path, and the outer four may follow each other in a path of their own.

By treating this disk after the manner of the perforated disk above described, many brilliant and surprising effects may be produced.

By holding one edge of the disk lightly between the thumb and finger, so that it will not revolve, but will be made to gyrate by the little crank, each button will describe a 3-8 inch circle, or a small oval, or an ellipse, as shown at 7. By allowing the disk to slip slowly between the thumb and finger, a series of double scrolls will be produced, as shown at 8.

On varying the speed of rotation by the application of more or less friction to the disk, a great variety of intricate and beautiful figures are produced. Examples are shown at 9, 10, and 11, Plate III. The effect shown at 11 is secured by allowing the edge of the gyrating disk to strike the finger once during each gyration. The luminous curve in this case appears to have a slow retrograde motion.

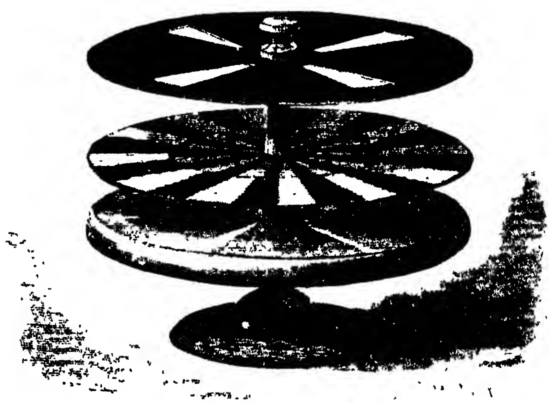
In Fig. 176 is shown a cardboard disk mounted loosely on the top spindle and provided with two series of black

radial bars, the inner series having 13 bars, the outer series having 12 bars. To the chuck inserted in the spindle is secured a black disk having four radial slits.

When the top is revolved and the lower disk is retarded, some very curious illusions will be produced. At times one part of the lower disk will appear to remain stationary, while the other part will appear to revolve. Again, the two series of radial bars will appear to rotate in opposite directions. Viewed in another way they appear curved.

By replacing the slitted disk with the perforated disk, and arranging the perforated disk so that it may be retarded

FIG. 176.



Radial Disks.

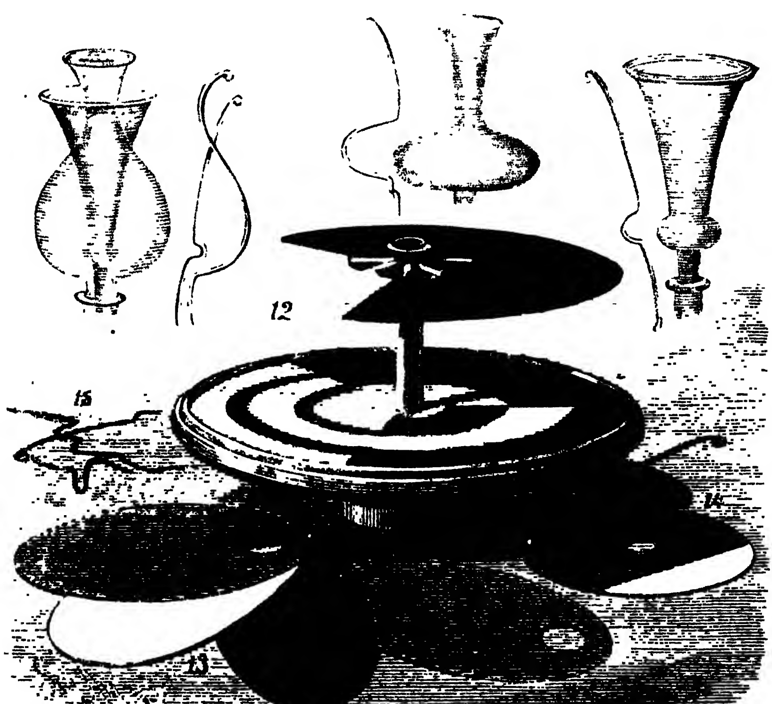
by the friction of the finger, some curious effects will be seen. The different rows of holes will appear to advance and recede in a very erratic way. Fig. 177, 12 to 15 inclusive, illustrate the well known and very interesting toy known as the chameleon top. This top is shown in this connection, as the beautiful experiments which have been adapted to it may be transferred with great advantage to the heavier top; 12 shows the top itself, with the black sector lifted out of its normal position to show the colored segments on the face of the top.

When the top is spun with the black sector resting on its face, a great variety of changes of hue may be produced

by retarding the sector, by touching the metallic radially ribbed disk attached to its center. This operation causes it to shift its position on the top, and expose the different colored segments in succession. Persistence of vision causes the segments to appear as circular bands of color, which constantly change.

When the colored paper ellipses shown at 13 are thrown

FIG. 177.



The Chameleon Top.

upon the top and touched by the finger, the colors are curiously blended.

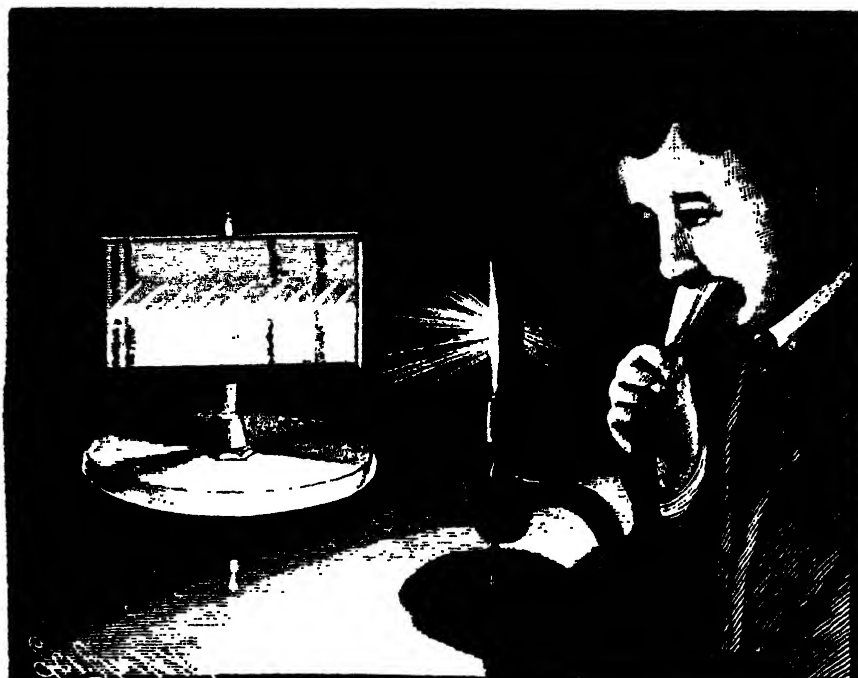
The tricolored disk shown at 14 is to be supported loosely on one of the wires shown at 15. This disk, when revolved, yields some very pretty effects. The wires shown at 15, when inserted in the hollow top spindle and revolved, produce the figures shown in the upper portion of the engraving, appearing like phantom vases, bowls, etc.

When this experiment is adapted to the large top, the wires are replaced by thin nickel-plated tubes, inserted in wooden pins fitted to the spindle of the top. The tubes are provided at their upper ends with small spherical knobs.

In addition to the experiments described, there are of course many others of equal interest which may be performed by means of a heavy top.

The engraving represents an attachment to the "scienti-

FIG. 178.



Top with Revolving Mirrors—Koenig's Manometric Flames.

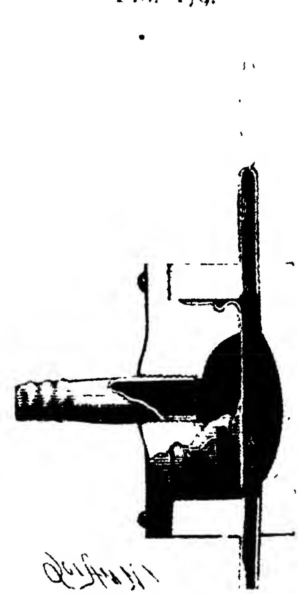
fic top," by means of which the beautiful and instructive experiments of Koenig may be readily repeated. The part of the apparatus carried by the top consists of two pieces of ordinary silvered glass (looking glass), 2½ by 5 inches, secured to opposite sides of a light wooden frame of the same size, and 3-4 inch thick, by means of strips of stout black paper attached to the frame and to the edges of the glasses. The upper and lower edges of the wooden frame are bored at the center to receive the rod inserted in the bore of the

top spindle. The frame fits the rod loosely, and is revolved by frictional contact with the rod and the upper end of the top spindle. This arrangement allows the mirror to revolve at a comparatively low rate of speed, the resistance of the air causing the mirror frame to slip on the rod.

It is necessary thus to provide for the slow rotation of the mirrors, as the flame points would be blended into a continuous band of light by the persistence of vision were the mirrors allowed to revolve as rapidly as the top.

The device for producing the variable flame is shown in perspective in Fig. 178 and in section in Fig. 179. It consists of a cell formed of two parts, one inserted in the other, and provided with an air chamber, covered by a diaphragm of very thin soft rubber, a gas pipe entering the lower side of the cell at one end of the diaphragm, and a fine gas burner inserted in the cell upon the same side of the diaphragm. A mouthpiece communicates with the air chamber of the cell through a flexible tube, and the gas pipe leading to the cell is connected with the house supply. The gas burner is provided with a narrow shade, which shields the eye of the observer from the direct light of the flame. The top having been set in motion, the mirror is applied and sounds are uttered in the mouthpiece. By viewing the reflection of the flame in the revolving mirror, it will appear as if formed of a regular series of pointed jets, the persistence of the successive images formed on the retina causing them to appear as if produced simultaneously.

FIG. 179.



Section of Diaphragm Cell.

The vibrations of the diaphragm due to the sound waves impinging upon it cause the gas to be pushed out of the burner in little puffs, which are not very noticeable when

the flame is observed directly, but which are clearly brought out when examined by the revolving mirror.

By employing a double mouthpiece, two sets of flame points of different lengths alternating with each other may be shown. Each vowel sound yields a characteristic series of flame points. A whistle will yield very fine points, while a very low bass note will produce scarcely more than a single point for each half revolution of the mirror.

HEAT.

Heat is the manifestation of an extremely rapid vibratory motion of the molecules of a body. An increase in the velocity and amplitude of the vibrations increases the temperature of the body. A heated mass can impart vibratory motion to the ether which fills space and permeates all bodies, and these wave motions of the ether are able to reproduce in bodies motions similar to those by which they were caused.*

The more obvious effects of heat are expansion, fusion, and vaporization. All bodies increase in volume when heated; gases being the most expansible, liquids next, and solids the least. Heat may partially or wholly balance molecular attraction. Hence it is that, when heated, solids first expand, then (if no chemical action occurs) soften and become liquid, and finally vaporize.† Liquids are changed into vapors, and gases are rarefied.

EXPANSION.

Expansion takes place in all directions. To render this phenomenon apparent, an elongated and attenuated body, such, for example, as a fine wire, is chosen and its linear expansion only is noted. Fig. 180 shows an instrument for exhibiting the linear expansion of a long thin wire, 1 and 2 being respectively front and side views. The instrument is provided with two series of hard rubber pulleys mounted on studs projecting from a board. A fine brass wire (No. 32) attached to the board at one end passes around the successive pulleys of the upper and lower series in alternation, the last end being connected with one end of a spiral spring, which is strong enough to keep the wire taut without

* "Heat a Mode of Motion," by John Tyndall, is an interesting popular treatise on this subject.

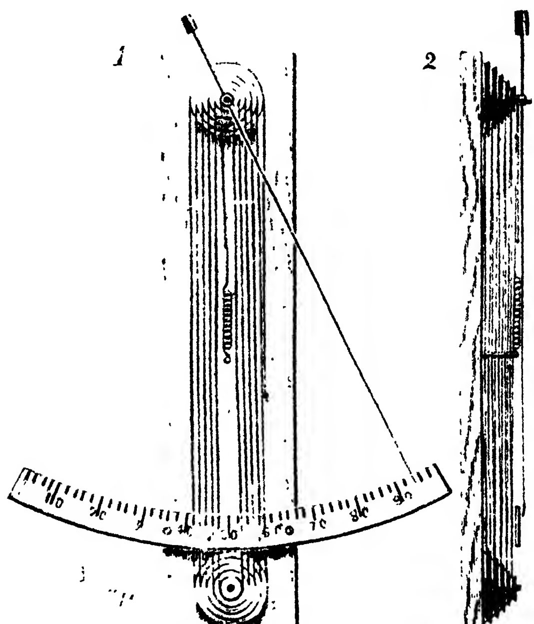
† Most organic bodies oxidize before the temperature of liquefaction is reached.

stretching it. The other end of the spring is attached to a stud projecting from the board. The pulleys are of different diameters, so that each series forms a cone. By this construction the wire of one convolution is prevented from covering the wire of the next.

The last pulley of the upper series is provided with a boss, to which is attached a counterbalanced index. A curved scale is supported behind the index by posts projecting from the board.

The series of pulleys are 12 inches apart, and there are

FIG. 180.



Metallic Thermometer.

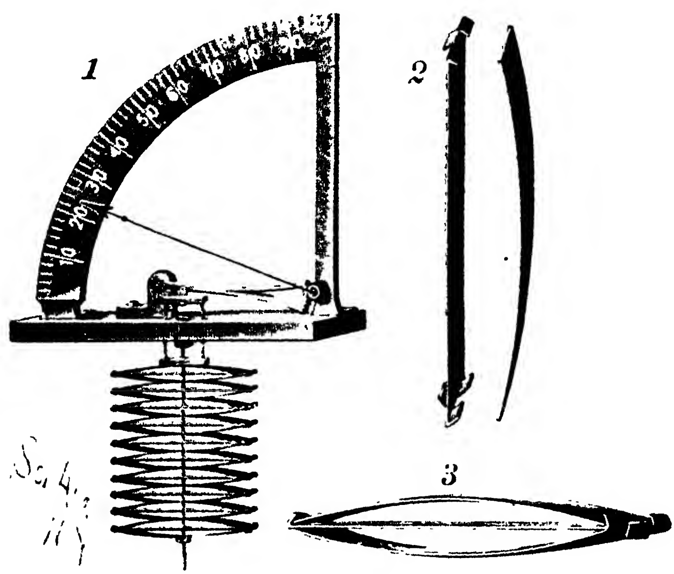
ten convolutions of wire, so that a small change of temperature produces sufficient expansion of the wire to cause a perceptible movement of the index. To increase the sensitiveness of the instrument, the wire is blackened by means of smoke or dead black varnish. An electric current passing through the wire heats it sufficiently to cause a deflection of the index; the amount of deflection depending, of course, upon the strength of the current.

SIMPLE THERMOSTAT.

Fig. 181 shows a simple thermostat which is capable of many useful applications. It is represented with an index and scale, but these are not essential for most purposes.

The instrument depends for its operation on the difference between the expansion of brass and steel. The linear expansion of brass is nearly double that of steel, so that when a curved bar of brass is confined at the ends by a straight bar of steel, the brass bar will elongate more than

FIG. 181.



Thermostat.

the steel bar when both are heated, and will in consequence become more convex.

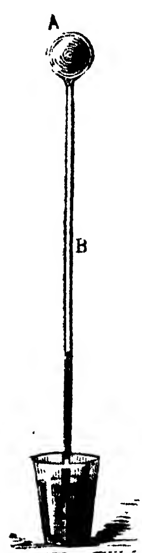
At 2 are shown two bars, the straight one being of steel, the curved one of brass. The steel bar is slit for a short distance in two places at each end, and the ears thus formed are bent in opposite directions to form abutments for the ends of the curved brass bars, two brass bars being held by a single steel bar, thus forming a compound bar, as shown at 3. Each compound bar is drilled through at the center. Ten or more such compound bars are strung together

loosely upon a rod, which is secured to a fixed support. A stirrup formed of two rods and two cross pieces rests upon the upper compound bar and passes upward through the support. Above the support it is connected by a link with a sector lever which engages a pinion on the pivot of the index. The use to which the thermostat is to be applied will determine its size and construction. It may be used in connection with kilns and ovens and for operating dampers, valves, and electric switches.

AIR THERMOMETER.

The air thermometer, consisting of an air bulb, A, and capillary tube, B, plunged in a colored liquid, shows changes in the volume of air due to expansion and contraction under changes of temperature by the rising or falling of the column of the colored liquid in the capillary tube. It is a sensitive thermometer, but of little practical value, on account of the variability of the volume of air by changes of pressure.

FIG. 182.

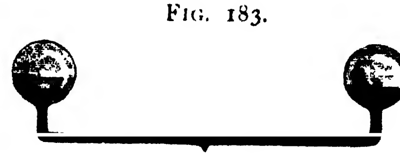


Air Thermometer.

PULSE GLASS.

The pulse glass (Fig. 183) is due to Franklin. It consists of two glass bulbs, formed on opposite ends of a tube bent twice at right angles, the system being partly filled with water, the air having been expelled by boiling the water before sealing the tube. When the bulb which contains the water is held in the hand, and the tube is placed in horizontal position, the rapid evaporation of the water by the warmth of the hand creates a pressure which causes the transfer of the water to the cooler bulb. The quick evaporation of the thin film of water adhering to the sides of the otherwise empty bulb increases the pressure, and causes a rapid ebullition of the water in the other bulb,

FIG. 183.



Pulse Glass.

and at the same time carries off the heat to such an extent as to produce a very decided sensation of cold.*

When the bulb is held at an inclination of about 40°, the water pulsates from one bulb to the other. The interior of the cool bulb becomes quickly dry, and evaporation in it therefore ceases. The water from the other bulb at once flows back into the lower one, to be again expelled by renewed expansion and evaporation.

FIG. 184.

The instrument operates continuously and very regularly when placed in a horizontal position upon a table, with one of the bulbs in the vicinity of a lamp, that is, within eight or ten inches of the flame, the other bulb being placed as far as possible away from the flame and shaded.

The straight form of pulse glass, shown in Fig. 184, exhibits the vaporization of water *in vacuo* to better advantage than the bent form.

When the bulb is held in the hand, the rapid evaporation, by the warmth of the hand, of the water flowing through the narrow neck of the tube and down the inner surface of the bulb creates a pressure of vapor, which finds exit through the neck of the tube, and bubbling up through the main body of the water, is condensed either in the water or above it. Sometimes the tube, when designed for use as a toy, contains the figure of an imp, which the ebullition of the water agitates violently.

THERMOSCOPIC BALANCE.

The action of the thermoscopic balance, shown in Fig. 185, is due to the facility with which liquids evaporate in a vacuum. A small amount of heat is sufficient to vaporize the liquid to the extent required to secure the desired action. The instrument is provided with a glass tube bent twice at right angles, and having a bulb blown on each end. The

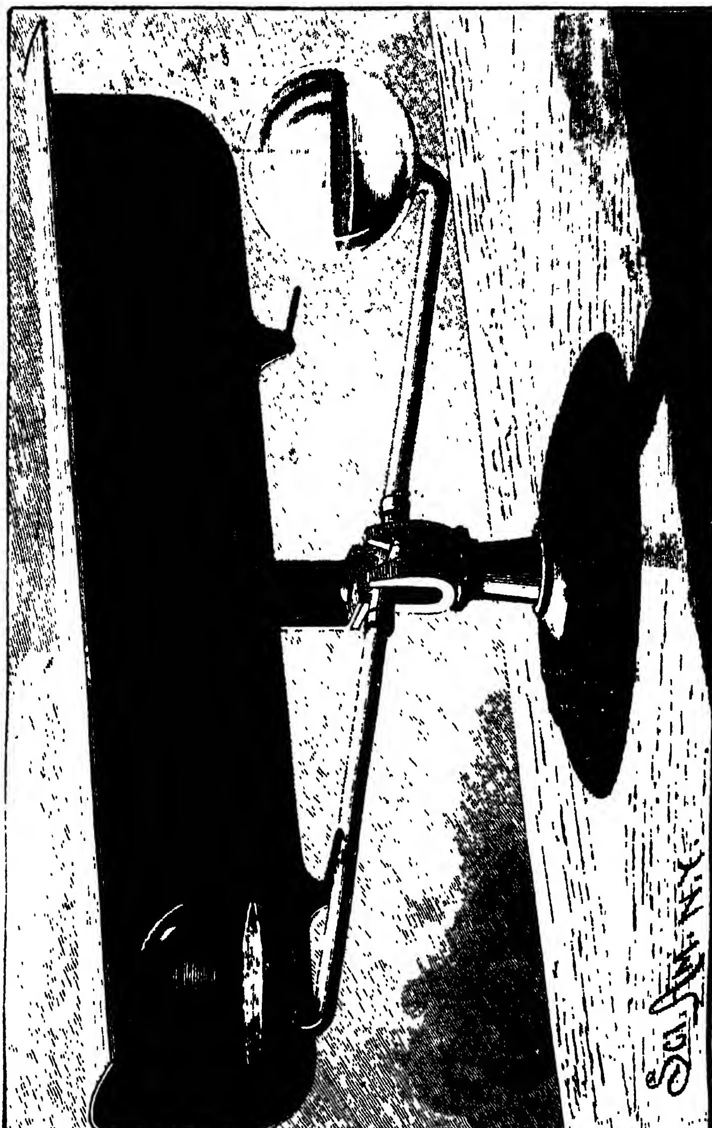
* This phenomenon is one of latent heat, a subject omitted here, but treated at length in text books on physics.

tube and the bulbs, like the pulse glass, are partly filled with water, and a vacuum is secured by boiling the water in the bulbs before sealing them. The center of the tube is furnished with V-pivots, which rest in bearings in the top of the forked column. The column also supports a metal screen, which is bright one side and black on the other. Two pins project from the screen to limit the movements of the glass tube and bulbs.

When the instrument is in use, the screen is placed toward the source of heat, and when radiant heat strikes the bulb which is unshielded by the screen, the water in that bulb is vaporized, and sufficient pressure is produced to drive the water upward into the bulb behind the screen. When a little more than half of the water has been in this manner forced from the lower to the higher bulb, the upper bulb preponderates. The tube and bulbs are supported on their pivot so as to secure unstable equilibrium, so that, when the upper bulb begins to descend, it completes its excursion at once, and exposes the full bulb to the radiant heat, at the same time carrying its empty bulb behind the screen, where it cools. The transfer of the water from the full bulb to the empty one now occurs as before. This operation is repeated so long as the bulbs are exposed to the action of radiant heat. The oscillations may be quickened by smoking the sides of the bulbs remote from the screen, and still greater rapidity of action may be secured by concentrating the heat on the bulbs by means of condensers or reflectors.

The principle of the thermoscopic balance has been utilized in the construction of an electric meter. To render it available for this purpose, a coil is inserted in each bulb above the water line and electric connections are provided, by which the current is sent through the coils in alternation as the bulbs tilt. The current thus commuted heats first one coil and then the other, causing the transfer of the water from one bulb to the other in the manner already described. Registering mechanism is provided which records the number of oscillations of the tube. The rapidity of the operation of the instrument is proportional to the strength of the current.

Fig. 185.



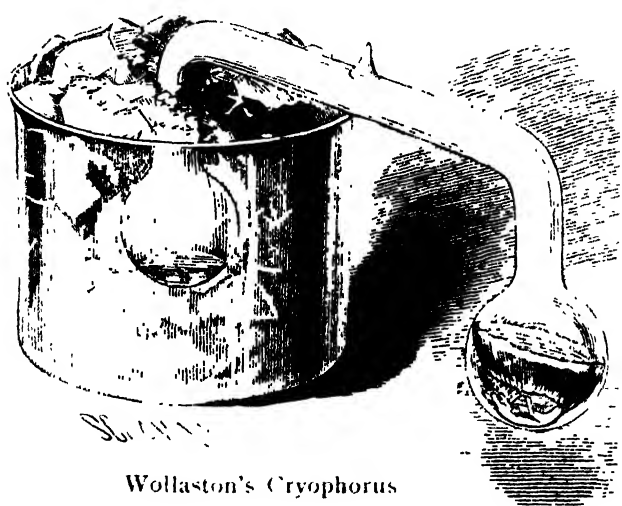
Thermoscopic Balance.

CRYOPHORUS.

Wollaston's cryophorus is similar in form and principle to the pulse glass, the only difference being that the tube connecting the two bulbs is made much larger, to avoid choking by ice—a thing sure to occur when the tube is of small diameter—the water vapor which is drawn toward the empty bulb (in a manner presently to be described) being condensed and frozen on the walls of the tube to such an extent as to entirely close it.

The cryophorus in process of construction is partly filled with water, which is boiled in the bulbs before sealing,

FIG. 166.



Wollaston's Cryophorus

to drive out the air. When the empty bulb of the apparatus is placed in a freezing mixture of ice and salt, for example, the evaporation of the water in the filled bulb, due to the cooling and condensation of vapor in the empty bulb, is rapid enough to carry off the heat to such an extent as to cause the water to freeze. Instead of employing the freezing mixture, a spray of ether or bisulphide of carbon may be projected upon the empty bulb with the same results.

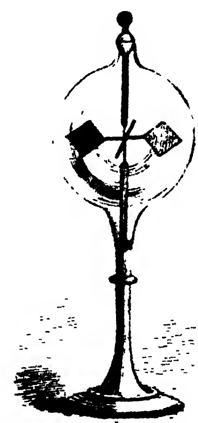
This is a very interesting experiment, illustrating the principle of freezing by rapid evaporation. It also exhibits the change of state of water from gaseous through liquid to solid condition.

RADIOMETER.

The radiometer is a heat engine of remarkable delicacy as well as great simplicity. It illustrates a class of phenomena discovered by Crookes, which are difficult to explain in a brief and popular way.*

The instrument consists of a very slight spider of aluminum supporting on the end of each of its four arms a very thin mica plate blackened on one side and silvered on the other side.

FIG. 187.



Radiometer.

The aluminum spider is provided with a jewel, which rests upon a delicate needle point supported at the center of the glass globe.

The spider is retained on its pivot by a small tube extending downward from the top of the globe. When placed in sunlight or near a gas or lamp flame, the vanes revolve rapidly.

An alum cell interposed between the radiometer and the source of light and heat allows the light to pass, but intercepts the heat rays. Under these conditions the vane will not rotate. An iodine cell, which is opaque to light, when arranged in the same way allows the heat rays to go through, and these cause the rotation of the vane.

TYNDALL'S EXPERIMENT ON RADIANT HEAT.

It often happens that students who desire to test for themselves the experiments of distinguished investigators are prevented from such instructive pleasures by the notion that, for delicate experiments, fine and expensive apparatus is required. Such apparatus is undoubtedly desirable and pleasant to work with, but where it is not to be had, a little courage and ingenuity may provide cheap substitutes which will perfectly answer the student's purpose. The crude apparatus herewith figured illustrates this fact.

* "The Principles of Physics," by Alfred Daniel, contains a clear explanation of the radiometer.

The interesting experiment of Tyndall on radiant heat was suggested to him by Prof. Bell's photophonic experiment, in which musical sounds are obtained by the action of an intermittent beam of light upon a solid body. Referring to this, Prof. Tyndall says:

"From the first I entertained the opinion that these singular sounds were caused by rapid changes of temperature, producing corresponding changes of shape and volume in the bodies impinged upon by the beam. But if this be the case, and if gases and vapors really absorb radiant heat, they ought to produce sounds more intense than those obtained from solids. I pictured every stroke of the beam responded to by a sudden expansion of the absorbent gas, and concluded that when the pulses thus excited followed each other with sufficient rapidity, a musical note must be the result. It seemed plain, moreover, that by this new method many of my previous results might be brought to an independent test. Highly diathermanous bodies, I reasoned, would produce faint sounds, while highly athermanous bodies would produce loud sounds—the strength of the sound being, in a sense, a measure of the absorption. The first experiment, made with a view of testing this idea, was executed in the presence of Mr. Graham Bell, and the result was in exact accordance with what I had foreseen."

The writer has successfully repeated Prof. Tyndall's experiment with the simple apparatus shown in the illustration (Fig. 188). Apparatus already at hand was utilized. A small sized bulbous glass flask, $1\frac{3}{4}$ inches in diameter, was mounted in a test tube holder, and placed behind a rotating pasteboard disk, 12 inches in diameter, having twelve apertures $1\frac{1}{2}$ inches wide and $1\frac{1}{4}$ inches long. Several flasks of the same capacity were provided and filled with the different gases and vapors, and stoppered, to be used at convenience. Near the disk was placed a common gas flame, and into the mouth of the flask was inserted one end of a long rubber tube, the other end being provided with a tapering ear tube, placed in the ear of the listener, whose position was sufficiently remote from the apparatus to avoid any possible disturbance from the revolving disk or the operator. The

FIG. 188.

Apparatus exhibiting the Action of Radiant Heat on Gaseous Matter.

disk being rotated so as to rapidly intercept the thermal and luminous rays of the gas flame and render the rays rapidly intermittent, the effect on the gases and vapors contained by the different bulbs was noted. Dry air produced no sound; moistened, it yielded a distinctly audible tone, corresponding in pitch with the rapidity of the interruptions of the thermal rays.*

Among gases tried, nitrous oxide and illuminating gas yielded the loudest sounds. Among vapors, water and sulphuric ether were most susceptible to the intermittent rays. A candle flame produced distinctly audible sounds in the more sensitive gases, and a hot poker replacing the gas flame yielded the same results.

By using an ordinary concave spun metal mirror, the heat of the flame was satisfactorily projected from a considerable distance. Considering the crudeness of the apparatus and the delicacy of the action which produces the sounds, it appears remarkable that any satisfactory results were obtained, and the experiment shows that any one interested in the finer branches of scientific investigation may often, with the exercise of a little care, enjoy, without material expense, those deeply interesting experiments.

REFLECTION AND CONCENTRATION OF HEAT.

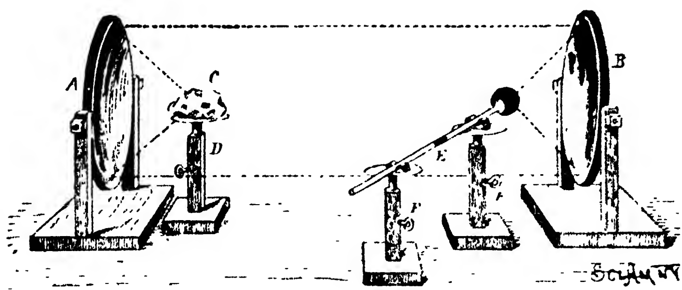
In this experiment the concave mirrors described in a previous chapter are employed in reflecting and concentrating heat.

Instead of placing the watch in the focus of the reflector, B, as in the sound experiment, an air thermometer, E, is supported upon two stands, F F, as shown in Fig. 189, with its bulb in the focus of the reflector. The bulb is smoked over a candle, and when it is nearly cold a drop of water or mercury is introduced into the capillary tube to serve as an index. The candle is removed until the drop in the tube ceases to move. It is then replaced. In a very short time the drop will be pushed outward by the expan-

* The tone to be expected from the gas or vapor when acted on by radiant heat may be determined by blowing through a tube against the apertured portion of the rotating disk.

sion of the air in the bulb. The candle is again removed, and when the drop has returned to the point of starting and ceased moving, a lump, C, of ice is placed on the stand, D,

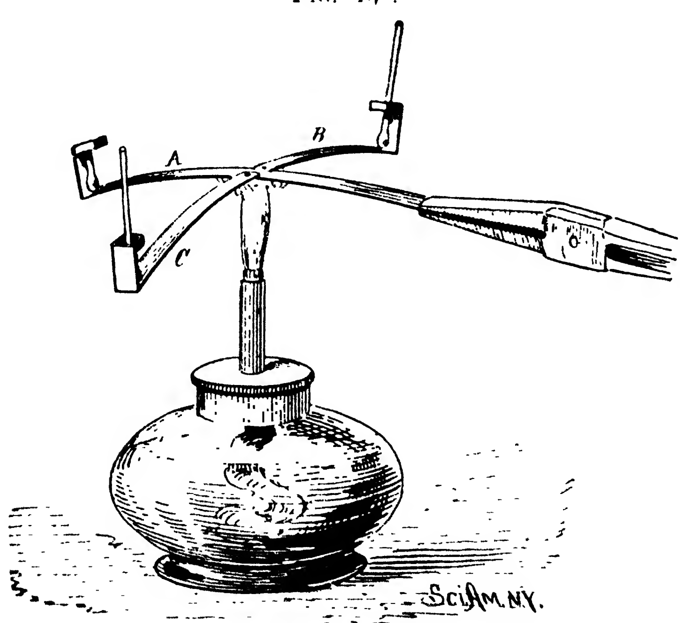
FIG. 189.



Reflection of Heat.

in the focus of the reflector, A. Immediately the air contracts in the thermometer and draws the drop in. Each of the two bodies is radiating, and receiving heat radiated from the other. But the ice radiates less than the bulb; hence the bulb gives out more than it receives, and the fall of temperature is shown by motion of the index.

FIG. 190.



Conduction of Heat

THE CONDUCTIVITY OF METALS.

The conductivity of metals for heat is admirably shown by the simple device illustrated in Fig. 190. To a strip, A, of iron are attached strips, B C, of brass and copper. The ends of all the strips are bent upward and inward, and the ends of the strips are split and curved to form loops for loosely holding matches, the sulphur ends of which rest upon the strips by their own gravity. The junction of the strips is heated as shown. The match on the copper strip ignites first, that on the brass next, and that upon the iron last, showing that, of the three metals, copper is the best conductor of heat and iron the poorest.

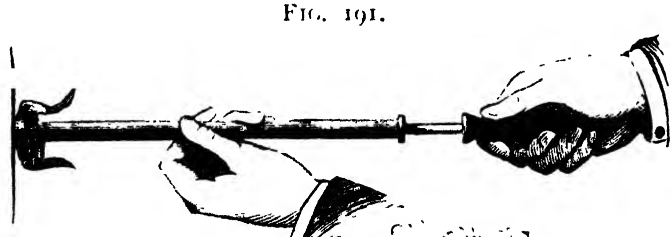
HEAT DUE TO FRICTION.

Every engineer having machinery in charge knows something of this subject. Badly proportioned or poorly lubricated journals often become intensely heated by undue friction. Occasionally a red hot journal is seen. Wherever there is friction there is heat. Often kinetic energy is transformed through friction into heat, which is dissipated by radiation into space, thus causing a loss of energy in a commercial sense, while in a physical sense it still exists, but in another form.

HEAT DUE TO PRESSURE AND COMPRESSION.

Hammering a nail rod until it is red hot and forging a nail without a fire is one of the feats of the blacksmith.

FIG. 191.



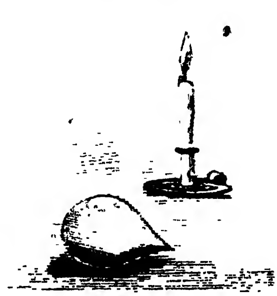
Pneumatic Syringe.

The compression of the iron by the blows of the hammer increases its temperature to such a degree as to render this possible. The impact of a bullet on a hard surface gener-

ates sufficient heat to melt the lead of which the bullet is formed. Numerous instances might be given of the generation of heat by the impact of solid bodies.

Gases are also heated by compression. By placing some dry tinder or cotton moistened with ether in the pneumatic syringe (pop gun), Fig. 191, and quickly forcing in the piston, so as to strongly compress the air contained in the barrel of the syringe, the temperature of the air will be raised sufficiently to ignite the tinder or cotton.

FIG. 192.



Candle Bomb.

FORCE OF STEAM.

The candle bomb, shown in Fig. 192, exhibits the explosive power of steam. It consists of a small bulb of glass filled with water and sealed. When the bomb is held in a candle flame by means of a wire loop, the water is converted into steam and an explosion occurs.*

The least expensive machine for applying to mechanical work the force exhibited by the candle bomb is the fifty-cent steam engine, shown in Fig. 193. It is a small and simple machine, but it is far more perfect than the steam engines of our forefathers. It will readily make 800 to 1,000 revolutions per minute. It is a wonderfully inexpensive example of the world's greatest motive power. Its construction is so well known that an extended description seems superfluous.

FIG. 193.

Fifty-cent Engine.

The standard which supports the crank shaft also forms the support of the trunnion of the oscillating cylinder. The piston is connected directly with the crank pin projecting from the fly wheel. The face of the cylinder which contacts with the standard forms the valve for admitting steam to the cylinder and releasing it after use. A passage in the standard conveys steam from the boiler to

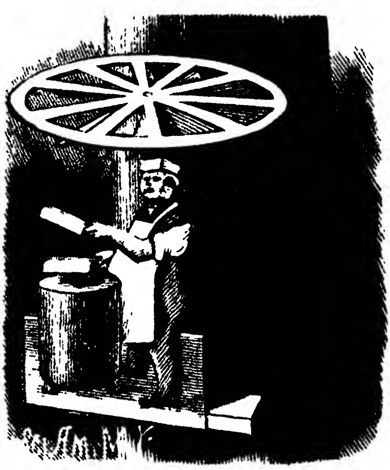
* A guard of some kind should be placed around the bomb to prevent injury to the experimenter.

the steam ports. A spiral spring on the trunnion draws the cylinder against the standard. The cylinder thus arranged is made to serve as a safety valve. A small alcohol lamp is used as a source of heat.

ASCENSIONAL POWER OF HEATED AIR.

The ascensional power of heated air is exhibited by the draught of every chimney. It is shown by the fire balloon and by the upward tendency of every flame. It is the prime factor in the propelling power of one of the most ancient of motors--the windmill: wind being only air rushing forward to take the place of air which is rising because it is rarefied by heat.

Fig. 194.



Hot Air Motor.

The power derived directly from an ascending column of heated air has never been utilized except as a motor for ventilators, for running mechanical toys, and to some extent for operating small mechanical signs.

The toy motor shown in the annexed engraving is too familiar to require description. It is generally placed over a lamp chimney or at the side of a stovepipe, where the rapidly ascending heated air may impinge on the inclined vanes. The air, acting on the vanes according to the well known law of the inclined plane, produces a lateral movement of each vane, and the vanes being restrained at the center of the wheel while free at their outer ends are compelled to move circularly.

HYGROMETRY.

The toy hygroscope serves to show approximately the hygrometric state of the atmosphere. One of the several forms in which it is made is shown in the annexed engraving. A perforated metal tube, projecting from the back of

the figure, contains a short piece of catgut cord, which is fastened in the rear end of the tube by closing the sides of the tube down upon it. The opposite end of the cord projects beyond the front of the figure, and is attached to the arm of the boy. In the hand of the arm thus supported is carried an umbrella. When the air is dry, the catgut cord retains its twist, and the arm holds the umbrella out of the position of use; but when the air becomes moist, the cord swells slightly, and untwists, and in so doing raises the boy's arm and brings the umbrella over his own head and over the head of his companion.

Fig. 195.

Hygroscope.

Another form of the same device consists of a house having two doors and containing two figures—a man with an umbrella and a woman in fair-weather dress; the figures being supported on opposite ends of a bar suspended centrally by a catgut cord. When the cord is untwisted by the action of moisture, the man with the umbrella sallies out; when the cord becomes dry, the man returns indoors and the woman appears.

Fig. 196.

Sensitive Leaf.

These simple, pleasing, and instructive toys illustrate the action of moisture on certain porous bodies, and are of interest, if not of actual use, to the meteorological observer. The action of the sensitive leaf shown in the engraving is also due to expansion by absorption of moisture. The leaf consists of a piece of thin gelatinized paper or gold beater's

skin, or even of gelatine, printed in some fantastic design, that of the mermaid being the favorite. When the leaf is laid upon the palm of the hand, the moisture of the hand is absorbed by one side of the leaf, and more in some places than in others, owing to imperfect contact with the hand. The moistened portions rapidly swell, thus warping the leaf, which twists and writhes in every possible direction, as if it were possessed of life. The leaf, being extremely thin, quickly becomes dry, so that the various contortions succeed each other rapidly.

CHEMICAL THERMOSCOPE, HYGROSCOPIC AND LUMINOUS ROSES.

FIG. 197.

Chemical Thermoscope.

The chemical thermoscope is made by sealing in a tube a solution of chloride of cobalt in dilute alcohol. When the tube is subjected to a temperature of 40° to 50° Fah., the solution becomes pink, and as its temperature is raised to 90° or 100°, it passes through various shades of purple, and finally becomes blue.

The same salt applied to an artificial flower, a rose for example, renders it visibly hygroscopic. When the air is humid, the rose is pink; and when the air is warm and dry, the rose will be purple or blue. A solution of the same salt constitutes one of the sympathetic inks.

The luminous rose shown in the same vase with the hygroscopic rose is a beautiful example of the wonderful property of storing light possessed by some bodies. The light-storing property is given the rose by a coating of luminous paint, the basis of which is sulphide of calcium. This rose, if exposed to a strong light during the day, will be luminous throughout the night.

FIG. 198.

Hygroscopic and Luminous Roses.

The exact nature of the change which takes place in the phosphorescent substance while exposed to the light* is unknown. It is supposed to be due to

some modifying action of the light, rather than chemical action. It has been ascertained that the phosphorescence takes place *in vacuo* as well as in air. Luminous paint has many practical applications. It is used on buoys, guide-posts, gates, etc., to render them visible at night. It is applied to match safes with obvious advantage.

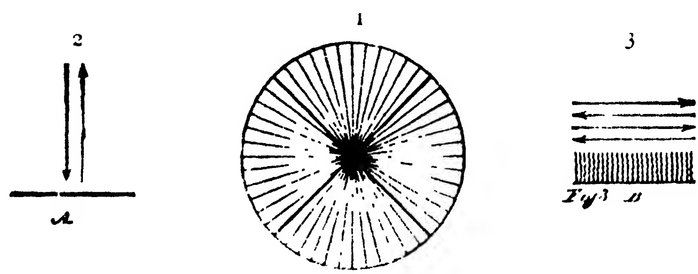
CHAPTER XI.

LIGHT.

Various hypotheses have been made regarding the nature and origin of light. The most important of these are the emission or corpuscular theory and the undulatory theory.

The emission or corpuscular theory of light was supported by Newton. It supposes light to consist of exceedingly small particles, projected with enormous velocity from a luminous body. Although this theory seems to have support in many of the phenomena of light, the velocity of light alone, as at present recognized, would seem to render

FIG. 199.



Comparison of Sound and Light Waves.

it untenable, however infinitesimal the projected particles might be. Tyndall has said that a body having the weight of one grain, moving with the velocity of light, would possess the momentum of a cannon ball weighing one hundred and fifty pounds and moving with a velocity of 1,000 feet a second; but the most delicate tests known to science have failed to show that light possesses any mechanical force.

The emission theory of light was opposed first by Hooke, Huygens, and Euler, who believed that the propagation of light was due to wave motion. All other eminent scientists supported Newton for one hundred years, but the undulatory theory was finally established beyond a question, by Young and Fresnel.

Sound is propagated by the alternate compression and rarefaction of air, the movements of the waves being parallel with the line of propagation. But not so with light. The vibrations of light are at right angles with its line of progression. These transverse vibrations, in ordinary white light, are in every conceivable direction across the path of the light beam. Their course is represented by Diagram 1, Fig. 199.

We can readily see how the longitudinal vibrations of air would affect the ear drum: 2 shows this action diagrammatically, the horizontal line, A, representing the tympanum, and the two arrows the forward and backward motion of the air wave.

Comparatively recent microscopical research has shown that the retina is studded with fine rods, as shown at B, which are susceptible of being influenced by the lateral movements of the particles in the wave front of a light beam.

The fact that light is wave motion necessitates the assumption of the existence of a medium far more subtile than ordinary matter, which pervades all matter and all space, and is in the interior of all bodies of whatever nature. It is thin, elastic, and capable of transmitting vibrations with enormous velocity. This hypothetical medium is called *ether*. Every luminous body is in a state of vibration, and communicates vibrations to the surrounding ether.

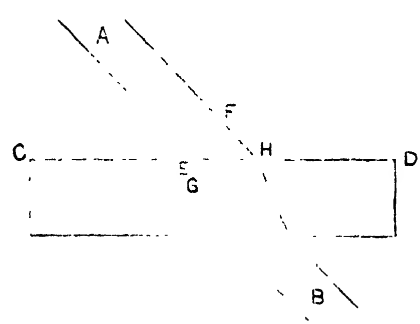
Although light is propagated in straight lines, its direction may be changed by reflection, by any body that will not wholly absorb it. The reflection of light from a mirror is a well known example of this. The direction of light may also be changed by refraction, by causing it to pass from one medium into another having a different density. By holding a strip of plate glass obliquely before a pencil or similar object, the bending of the light beam is shown by the apparent lateral displacement of the object.

Lewis Wright, in his excellent work on light, gives Huygens' explanation of refraction as follows:

"Any beam of light has a wave front across it, and it is obvious that in meeting any refracting surface obliquely,

one part of this wave front will meet it before another. Conceive, then, that while the ether permeates the open structure of all matter, it is still hindered in its motions by it, as wind is hindered, but not stopped, by the trees. Then trace a ray, A B (Fig. 200), to the refracting surface, C D, marking off the assumed length of its waves by the transverse lines. The front will be retarded at E before it is retarded at F, and we may assume the retardation is such that the wave in the denser medium is only propagated to G, while in the rarer medium it reaches H. It is plain that the beam must swing round; but when the side, F, also reaches the denser medium, the whole will be retarded alike and the beam

FIG. 200.



Refraction.

will proceed as before, only slower and in a different direction. The theory exactly fits all the phenomena."

As the beam emerges from the denser medium, the reverse of what has been described occurs, and, provided the refracting medium is of uniform thickness and density, the beam proceeds in a path parallel with its former course.

In lenses and prisms the emergent beam takes an oblique path, and in the case of lenses, either convergent or divergent, according to the kind of lens and the position of the lens relative to the object.

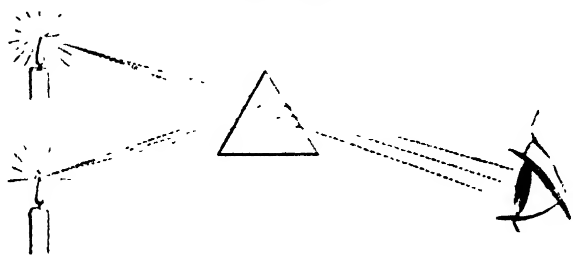
PRISMS.

Any refracting body having plane faces inclined to each other is known as a prism. A light beam passing through such a body is permanently deflected. For example, a candle

viewed through a prism placed as shown in Fig. 201 will appear to the observer in an elevated position. The light in this case is twice refracted, once on entering the glass, and again on leaving it.

The toy known as the polyprism consists of a plano-convex glass having a number of plane facets on its convex side.

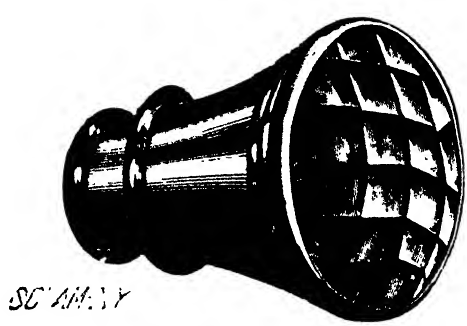
FIG. 201.



Course of Light through a Prism.

The facets being at slightly different angles with the plane face of the glass, the rays are refracted differently at each facet, thus producing as many images as there are facets. One man seen through this instrument appears like an assemblage. A coin viewed through it is multiplied as

FIG. 202.



Polyprism.

many times as there are facets, and a grate fire appears like the conflagration of a city.

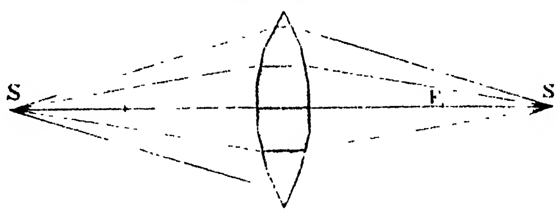
This toy illustrates in a crude way the principle of the convex lens. The several divisions of the prism are able to so refract a beam of light as to render it convergent, that is to say, each division of the prism will bend as much of the

beam as it receives, so that all of the light passing through the prism will be concentrated upon one spot, which will correspond in size with one of the facets. This spot marks the principal focus, a point at which the rays cross, and beyond which they diverge.

LENSES.

A lens may be regarded as an infinite number of prisms of gradually increasing angles arranged around an axis.

FIG. 203.

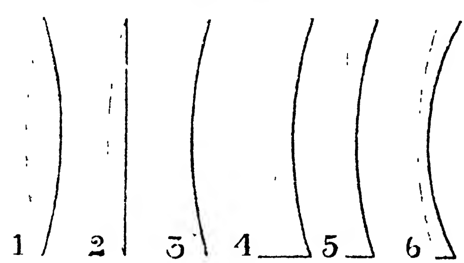


Hypothetical Lens.

This idea is illustrated by Fig. 203, in which is shown a hypothetical lens formed of prisms of different angles.

Rays of light proceeding from the point, S, to the lens are refracted differently, those meeting the outer portion of the lens being more deflected than those passing through the inner portions, while the rays coinciding with the axis

FIG. 204.



Forms of Lenses.

are not refracted. The emergent rays converge to the point, S′. Where there is an infinite number of inclined surfaces, the lens will have spherically convex surfaces.

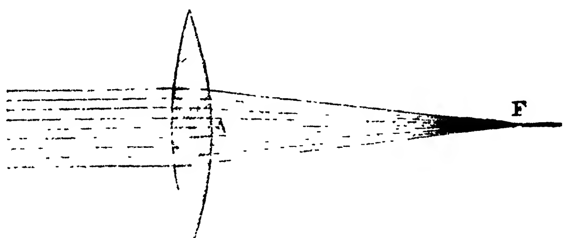
Of converging or magnifying lenses there are four forms, three of which are shown at 1 2, 3, in Fig. 204; 1 being a double convex lens, 2 a plano-convex, and 3 a convex menis-

cus. The fourth form, which is a double convex with curved sides of different radii, is known as a crossed lens.

Of diverging or diminishing lenses there are three forms, which are also represented in Fig. 204; 4 being a double concave, 5 a plano-concave, and 6 a concave meniscus.

Parallel rays on entering a double convex lens are re

FIG. 205.

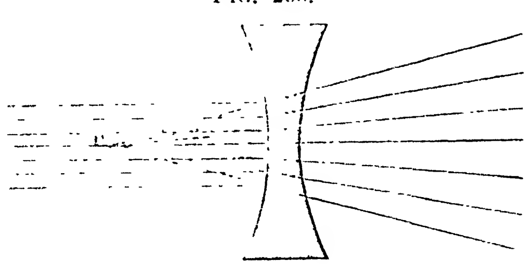


Principal Focus of a Convex Lens.

fracted, and on leaving the lens they are again refracted so that they all converge at the point F, which is the principal focus. The focal length of the lens is the distance from the lens to the focal point.

When light proceeds from a point and is rendered convergent by a lens, as shown in Fig. 203, the point to which the rays converge and the point from which the light emanates

FIG. 206.



Principal Focus of a Concave Lens.

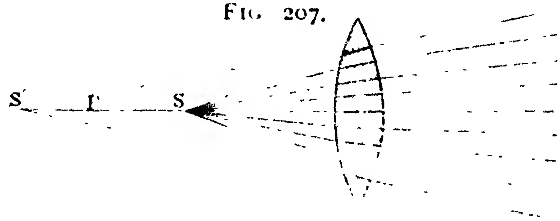
mark the *conjugate foci* of the lens. Light proceeding from the point, S′, will converge to the point, S, and in like manner light proceeding from S will converge to the point, S′.

A concave lens renders a parallel beam divergent, an action which is the reverse of that of the convex lens. If the divergent rays, after passing through a concave lens, are produced backward, as indicated by the dotted lines in

Fig. 206, they will meet in the point, F, which is called the principal focus.

Rays of light which converge toward the point, S', Fig. 207, before refraction, will, after refraction, converge to the

FIG. 207.

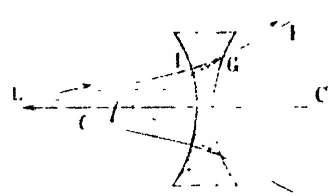


Converging Rays, Convex Lens.

point, S, between the principal focus, F, and the lens, and light emanating from the point, S, will diverge after passing through the lens.

Converging rays passing through a concave lens will

FIG. 208.

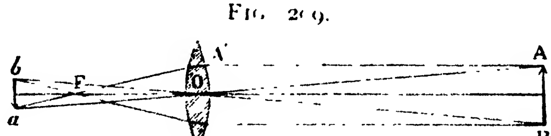


Diverging Rays, Concave Lens.

become less convergent or parallel according to the distance of the point toward which they converge.

Rays proceeding from the point, L (Fig. 208), to and through the concave lens are rendered more divergent. If,

FIG. 209.



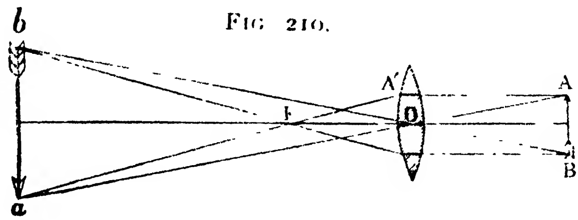
Real and Diminished Image.

in this case, the divergent rays, after passing through the lens, are produced backward, as indicated by dotted lines, they will converge toward the point, *l*, between the principal focus, C, and the lens.

An object, A B (Fig. 209), placed in front of a convex lens at a distance greater than its principal focal length will

have a real image, *a b*, on the other side of the lens This image is inverted and may be either larger or smaller than the object. By holding a double convex lens between the object and a white wall or screen, the image may be seen.

FIG. 210.

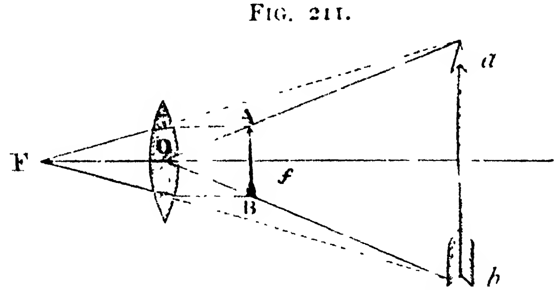


Real and Magnified Image.

By changing the relative distances of the object, the lens, and the screen, the size of the image may be varied. In Fig. 209 the object is distant more than twice the focal length of the lens. The photographer's camera exemplifies this principle.

In Fig. 210 is illustrated a case in which the lens is nearer the object, A B. A magnified real image is produced. In this case the distance of the object is greater than the single focal length of the lens, but less than twice its focal length. The projecting lantern exemplifies this principle.

FIG. 211.



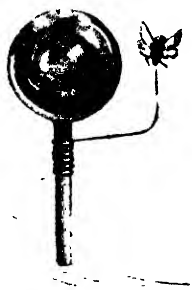
Virtual Image, Convex Lens.

When an object, A B (Fig. 211), is placed between the lens, O, and its principal focus, *f*, a virtual image, *a b*, is formed which is erect and magnified, and which appears at a greater distance than the object. This figure illustrates the manner in which objects are viewed by an ordinary magnifying hand glass.

One of the simplest of toys illustrating the action of convex lenses is the water bulb magnifier.

It is a small hollow sphere of glass filled with water and provided with a pointed wire arm for supporting the object to be examined. It is a Coddington lens lacking the central diapraghm. It answers very well as a microscope of low power, and illustrates refraction as exhibited by glass lenses. It receives the rays from the object placed within its focus, and refracts them, rendering them convergent upon the opposite side of the bulb; but all of the rays do not converge exactly at one point, so that the image, except at the center of the field, is distorted and indistinct. This effect is spherical aberration.

FIG. 212.



Water Bulb Magnifier

MIRRORS.

The convex cylinder mirror shows an ordinary object very much contracted in one direction.

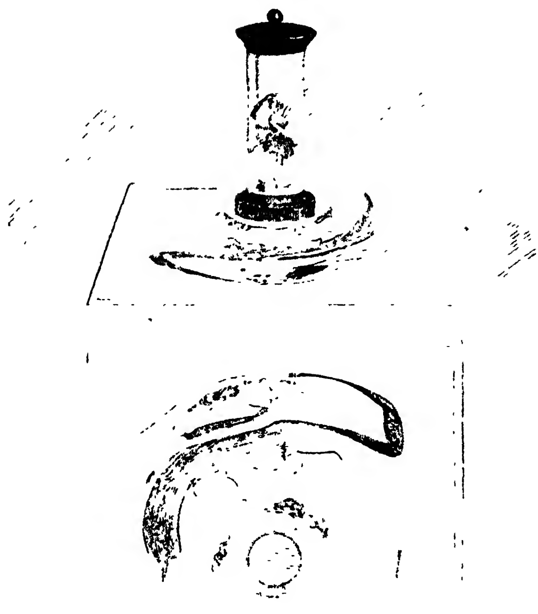
The pictures accompanying these mirrors are distorted to such an extent as to render the object unrecognizable until viewed in the mirror, which corrects the image.

By tracing the incident ray from any point in the picture to a corresponding point in the image in the mirror, then tracing the reflected ray from the same point in the mirror to the eye, it will be found that in this, as in all other mirrors, the simple law of reflection applies; that is, that the angle of incidence and the angle of reflection are equal.

The concave cylindrical mirror (Fig. 214) is the reverse of the mirror just described. It produces a laterally expanded image of a narrow picture, and while the convex cylindrical mirror disperses the light from a distant source, the concave mirror renders it convergent; but, as in the case of the water bulb, the reflected rays do not focus at a single point, but cross each other, forming caustic curves. These curves may be exhibited by placing an ordinary cylindrical concave mirror edgewise on a white surface, and arranging a small light, such as a candle or lamp, a short

Fig. 213

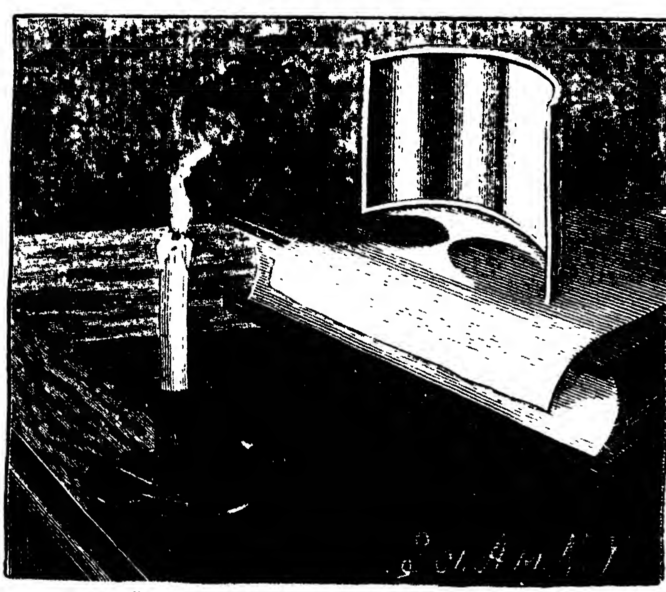
a



b

a, Convex Cylindrical Mirror. *b*, Distorted Picture to be viewed in Mirror

Fig. 214.



Concave Cylindrical Mirror, Caustics.

distance from the mirror, as shown in the engraving. The same phenomenon may be witnessed by observing a glass partly filled with milk, arranged in proper relation to the light. The inner surface of the glass serves as a mirror, and the surface of the milk serves the same purpose as the white paper. A cylindric napkin ring will show the curves under similar conditions. In fact, any bright concave cylindrical surface will do the same thing.

A convex spherical mirror distorts to a remarkable

FIG. 215.

Spherical Mirror.

degree. A silvered glass globe held in the hand yields an image something like that shown in the engraving.

The size of the image depends upon the distance of the mirror, and is always less than that of the object. The farther the object is, the smaller is its image. This explains the distortion of the image, which appears to be behind the mirror.

The spherical concave mirror produces effects which are the reverse of those just described if the object be nearer than the principal focus. In this case, as in the other, the virtual image appears behind the mirror, and is a magnified

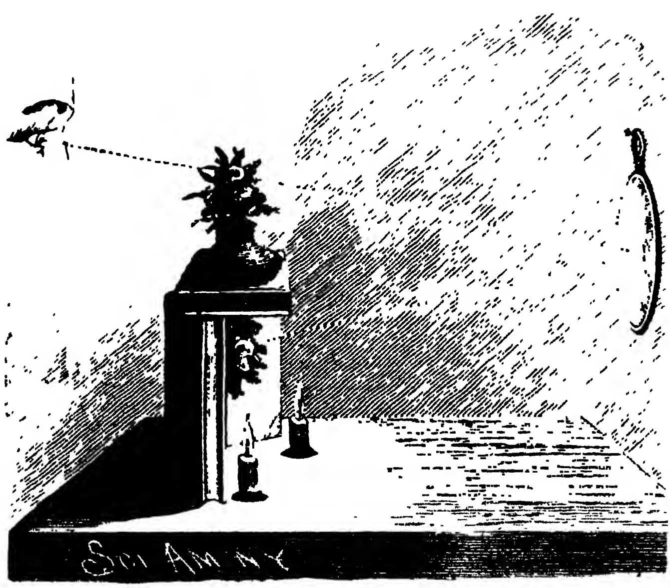
one. The image which appears in front of the concave mirror may be either larger or smaller than the object itself, depending upon the position of the object relative to the mirror and the observer.

It is inverted, and is formed in the air. A candle placed between the center of curvature of the mirror and the principal focus forms an inverted image in air, which is larger than itself.

PHANTOM BOUQUET.

The phantom bouquet, an interesting and very beautiful optical illusion, is produced by placing a bunch of flowers

FIG. 216.



Concave Mirror, Phantom Bouquet.

(either natural or artificial) in an inverted position, behind a shield of some sort, and projecting its image into the air by means of a concave mirror. A magnifying hand glass answers the purpose, if of the right focal length, and a few books may serve as a shield. Two black-covered books are placed upon one end and arranged at an angle with each other, and a third book is laid horizontally on the ends of the standing books. The bouquet is hung top downward in the angle of the books, and a vase is placed on the upper book, over the hanging bouquet.

The concave mirror is arranged so that the prolongation of its axis will bisect the angle formed by lines drawn from the top of the vase and the upper part of the suspended bouquet, and it is removed from the bouquet and vase a distance about equal to its radius of curvature.

A little experiment will determine the correct position for the mirror. When the proper adjustment is reached, a wonderfully real image of the bouquet appears in the air over the vase. It is necessary that the spectator shall be in line with the vase and mirror. With a good mirror and careful adjustment, the illusion is very complete. The bouquet being inverted, its image is erect. A very effective way of illuminating the bouquet, which is due to Prof. W. Le Conte Stevens, of Brooklyn, is shown in the engraving. It consists in placing two candles near the bouquet and behind the shield, one candle upon either side of the bouquet. In addition to this, he places the entire apparatus on a pivoted board, so that it may be swung in a horizontal plane, allowing the phantom to be viewed by a number of spectators.

This simple experiment illustrates the principle of Herschel's reflecting telescope. In that instrument the image of the celestial object is projected in air by reflection and magnified by the lenses of the eyepiece.

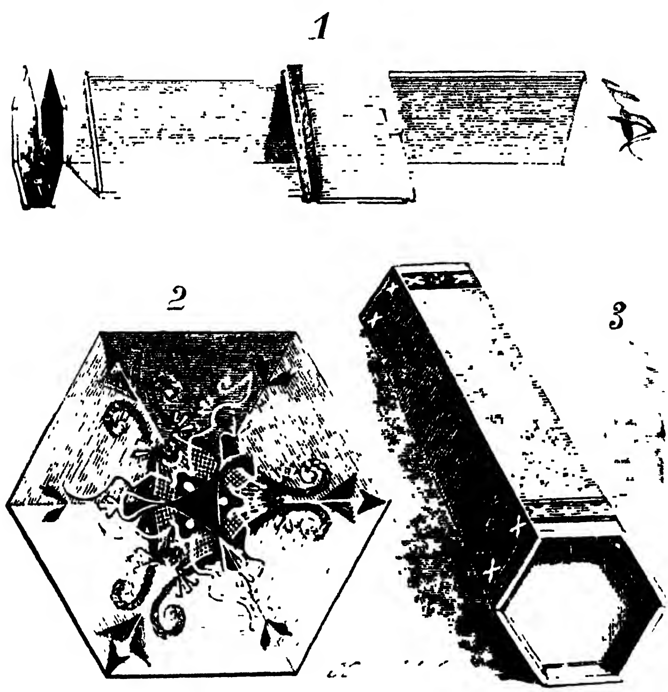
MULTIPLE REFLECTION.

The kaleidoscope is one of the most beautiful and inexpensive of optical toys. It can be purchased in the ordinary form for five or ten cents. It is sometimes elaborately mounted on a stand and provided with specially prepared objects. It consists of a tube containing two long mirrors commonly formed of strips of ordinary glass, arranged at an angle of 60°, with a plain glass at the end of the mirrors, then a thin space and an outer ground glass, the space being partly filled with bits of broken glass, twisted glass, wire cloth, etc. The mirrors may be arranged at any angle which is an aliquot part of 360°. When the mirrors, *a b*, are inclined at an angle of 60°, as in the present case, the object, *c*, together with the five reflected images, will form a hexag-

onal figure of great beauty, which may be changed an infinite number of times by turning the instrument so as to cause the bits of glass, etc., to fall into new positions.

The images adjoining the object are formed by the first reflections of the object. The images in the second sectors are formed by second reflections, and two coincident images

FIG. 217.



1, Parts of Kaleidoscope 2, The Figure. 3. Kaleidoscope.

in the sector diametrically opposite the object are formed by third reflections.

In most kaleidoscopes a third mirror is added, which multiplies the effects, and in the best instruments an eye lens of low power is provided.

ANALYSIS AND SYNTHESIS OF LIGHT.

An ordinary glass prism, such as may be purchased for fifty cents, is sufficient for the resolution of a beam of white sunlight into its constituent colors. By projecting the dispersed beam obliquely upon a smooth, white surface, the spectrum may be elongated so as to present a gorgeous

appearance. It is not difficult to understand that whatever is exhibited in the spectrum must have existed in the light before it reached the prism, but the recombining of the colors of the spectrum so as to produce white light is of course conclusive.

The colors of the spectrum have been combined in several ways, all of which are well known. Newton's disk does it in an imperfect way by causing the blending, by persistence of vision, of surface colors presented by a rotating

FIG. 218.

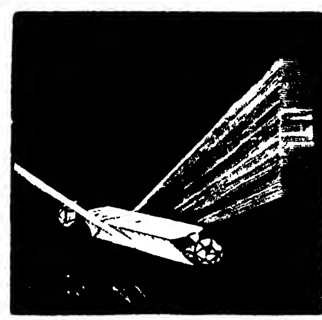
Simple Rocking Prism.

disk. Light from different portions of the spectrum has been reflected upon a single surface by a series of plane mirrors, thus uniting the colored rays forming white light. The colored rays emerging from the prism have been concentrated by a lens upon a small surface, the beam resulting from the combination being white. Besides these methods, the spectrum has been recombined by whirling or rocking a prism; the movement of the spectrum being so rapid as to be beyond the power of the eye to follow, the retina receiv-

ing the impression merely as a band of white light, the colors being united by the superposing of the rapidly succeeding impressions, which are retained for an appreciable length of time.

The engravings show a device to be used in place of the ordinary rocking prism. It is perfectly simple and involves no mechanism. It consists of an inexpensive prism, having attached to the knob on either end a rubber band. In the present case the bands are attached by making in each a short slit and inserting the knobs of the prisms in the slits. The rubber bands are to be held by inserting two of the fingers in each and drawing them taut. The prism is held in a beam of sunlight, as shown in Fig. 218, and with one finger the prism is given an oscillating motion. The band of light thus elongated will have prismatic colors at opposite ends, but the entire central portion will be white. To show that the colors of the spectrum pass over every portion of the path of the light, as indicated by the band, the prism may be rocked very slowly.

FIG. 219.



The Spectrum.

An ordinary prism may be made to exhibit several Fraunhofer's lines by arranging it in front of a narrow slit, through which a beam of sunlight is admitted to a darkened room. One side of the prism in this experiment must be adjusted at a very small angle with the incident beam. The spectrum will contain a number of fine dark lines, known as Fraunhofer's lines.

These lines tell of the constitution of the sun. The principle illustrated by this experiment is the one upon which the spectroscope is based.*

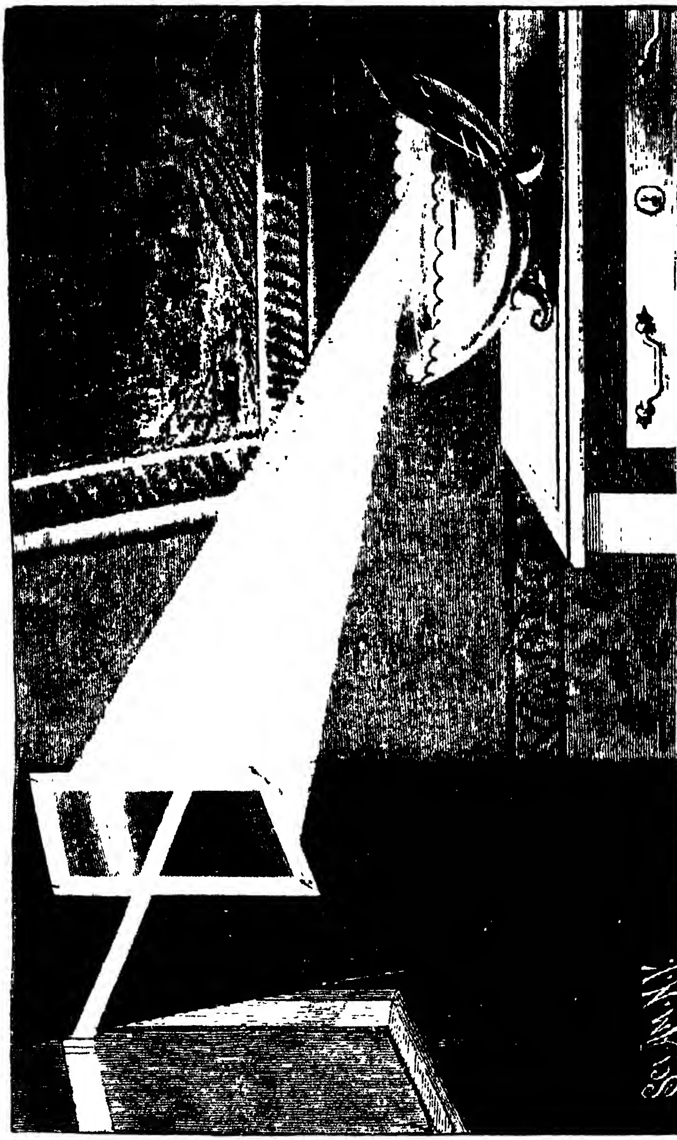
SIMPLE METHOD OF PRODUCING THE SPECTRUM.

Color is a sensation due to the excitation of the retina by light waves having a certain rate of vibration. Those

* For further information on this subject the reader is referred to "Studies in Spectrum Analysis," by J. Norman Lockyer.

having the highest rate capable of affecting the eye are perceived as violet, while those of the lowest rate are perceived as red. According to Ogden Rood's "Modern Chromatics," the rate of the former is 757 billions of waves per second,

FIG. 220.



Simple Apparatus for producing the Spectrum.

that of the latter is 395 billions of waves per second, and between these extremes are ranged waves of every possible rate, representing as many colors. When light waves of all periods are mingled, there is no color—the light is white.

Newton discovered a way of resolving white light into its constituent colors. He made exhaustive experiments with prisms, first producing the gorgeous array of colors known as the spectrum, then recombining the colored rays by means of another prism producing white light. He found that the colors of the spectrum were simple, *i. e.*, they could not be further decomposed, and he also demonstrated that the red rays were the least and the violet rays the most refrangible.

The solar spectrum is always a delight to the eyes of every person having normal eyesight, and it is a simple matter to produce it by means of a prism. When a prism is not available, it may be produced in the manner illustrated by Figs. 220 and 221. This method is inexpensive, and yields a large spectrum. The materials required are a piece of a plane mirror, five or six inches square, a dish of water, and a sheet of white paper or a white wall. The mirror is immersed in the water and arranged at an angle of about 60°; this angle, however, may be varied to suit the direction of the light. The incident beam received on the mirror is refracted on entering the water and dispersed. It is further dispersed upon emerging from the water. By causing the reflected beam to strike obliquely upon the white paper or wall, the spectrum thus produced may be made to cover a large surface.

Fig. 221.

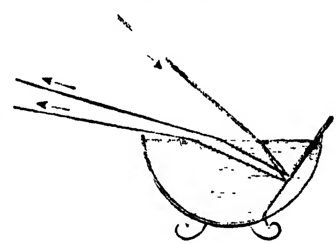


Diagram of Spectrum Apparatus.

Should the sun be too high or too low, the proper direction may be given to the incident beam by means of a second mirror held in the hand. The diagram, Fig. 221, shows the direction of the rays.

Some very interesting absorption experiments may be made in connection with this simple apparatus. For example, colored glass, or sheets of colored gelatine, may be placed in the reflected beam. If red be placed in the path of the beam, red light, with perhaps some yellow, will pass through, while the other colors will be absorbed, and will not, therefore, appear on the wall. With the other colors

the same phenomenon is observed. Each colored glass or gelatine is transparent to its own color, but opaque to other colors. It will be observed that few bodies have simple colors.

In a similar manner a piece of red paper or ribbon placed in the red portion of the spectrum will reflect that color, but if placed in some other part of the spectrum it will appear dark, the other colors being absorbed or quenched by the colored surface. It is seen by these experiments that when light passes through a colored glass or film, it does not retain all its colors. It is simply a matter of straining out every color except that to which the glass or film is transparent. In reality only a small part of all the light striking the colored glass passes through it.

In the above experiment it is essential to avoid all jarring of the water, as ripples upon its surface defeat the experiment. If it is possible to so place the dish as to avoid jarring, the ripples may be prevented by suspending a transparent plane glass horizontally, so that its under side will just make contact with the surface of the water.

NEW CHROMATROPE.

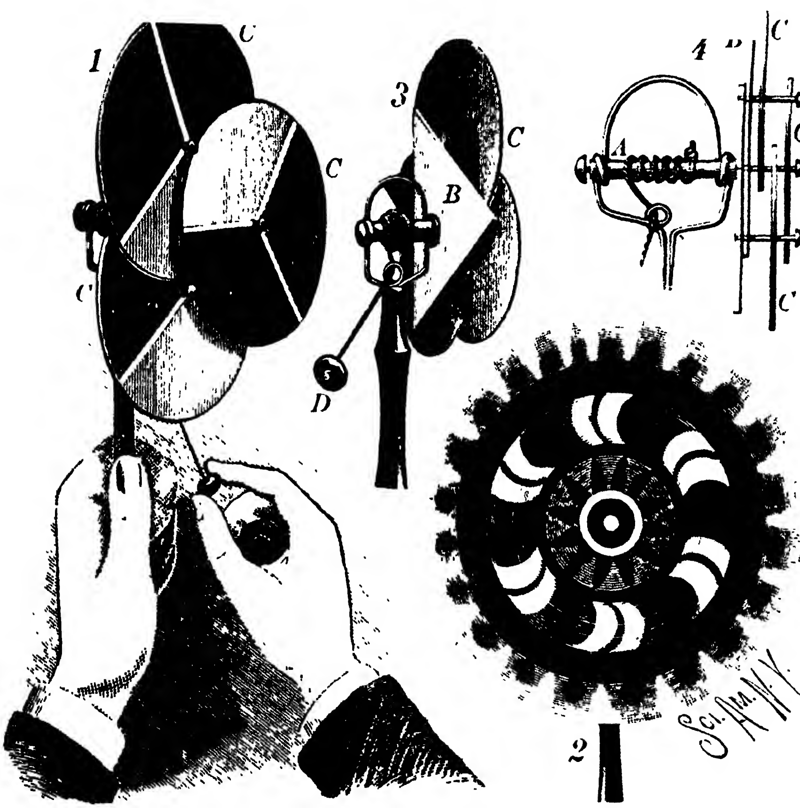
A novel toy which illustrates some of the phenomena of color is illustrated by Fig. 222. Upon the spindle, A, is secured a star, B, formed of two triangular pieces of pasteboard arranged so that their points alternate. One triangle is red, the other bluish green—complementary colors, which produce white when they are blended by the rotation of the star. In the angles of one of the stars are secured wire nails, which serve as pivots for the three disks, C, as shown at 1 and 4. Each disk is divided into three equal parts, which are colored respectively red, green, and violet. The disks overlap at the center of the star, B.

Around the spindle, A, is wound a cord which passes through the loop formed in the star frame in which the spindle is journaled, and is provided at its end with a button, D. By pulling the cord, the star, B, is whirled first in one direction and then in the other. As the series of disks, C, turn, the colors are blended in different ways, according to

the relative arrangement of the different sections. All the phenomena of the blending of surface colors are illustrated by this simple toy. At times the center will be a fine purple, while the outer part is green. At other times some portions of the color disk presented by the rotating disks are white, showing that a proper mixture of the three primary colors yields white light.

At the instant of the change of rotation from one direc-

FIG. 222.



Chromatrope.

tion to the other, the arrangement of the disks is such as to present beautiful symmetrical figures. All the changes of color in the toy in its normal condition are, of course, accidental.

When it is desired to try the blending of any of the colors, when arranged in a particular way, the disks may be

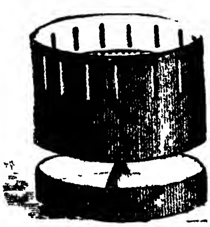
prevented from turning on their pivots by stretching over each disk a small rubber band.

The maker of this simple toy has succeeded in securing colors which produce remarkably good effects.

PERSISTENCE OF VISION.

The zoetrope, or wheel of life, is a common, but interesting, optical toy. It depends for its curious effects upon the persistence of vision. It consists of a cylindrical paper box mounted on a pivot, and having near its upper edge a series of narrow slits, which are parallel with its axis. Against the inner surface of the wall of the box is placed a paper slip, carrying a number of images of the same object arranged in as many different positions, each image differing slightly from the adjoining images, the successive positions of the several images being such as to complete one entire motion or series of motions.

FIG. 223



Zoetrope.

When these pictures are viewed through the slits, as the box is turned, the eye glimpses the figures in succession, and retains the image of each during the time of eclipse by the paper between the slits and until the next figure appears. The images thus blend into each other, and give the figure the appearance of life and action.

Some very interesting studies for the zoetrope have been produced by the aid of instantaneous photography.

IRRADIATION.

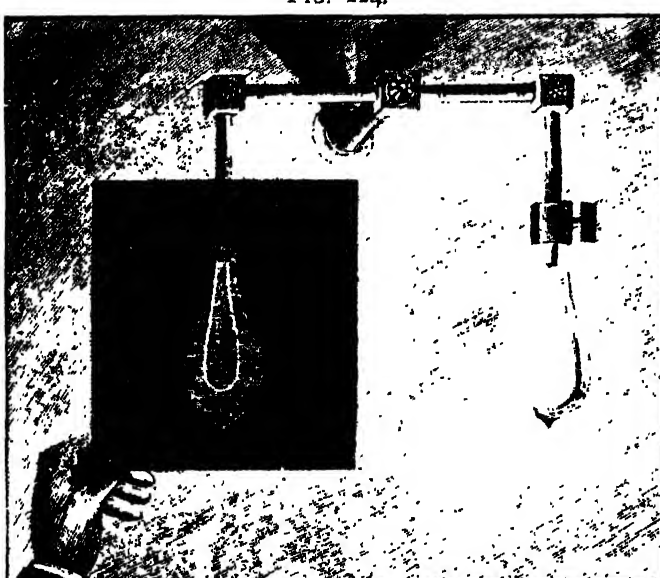
Brilliantly illuminated white surfaces and self-luminous bodies, when emitting white light, appear to the eye much larger than they really are. In nature examples of this phenomenon are presented by the sun, moon, and stars. The sun, viewed with the naked eye, appears very much larger than when the light is modified by a smoked glass. The crescent of the moon appears to project beyond the moon's periphery; and the stars, which are mere points of light even when viewed through the largest telescope, appear to the eye to have a disk of some size.

This phenomenon—known as irradiation—is due to the stimulation or sympathetic action of the nerves of the retina adjoining those which actually receive the image.

The ends of pieces of iron heated to incandescence by the blacksmith for welding seem to be unduly enlarged—an appearance due to irradiation.

Without doubt the most striking illustrations of irradiation are to be found in electric illumination. The electric arc, which is no larger than a pea, appears to the eye as large as a walnut; and the filament of an incandescent lamp, which is scarcely as large as a horsehair, appears as large as

Fig. 224.



An Example of Irradiation.

a small lead pencil. In viewing an ordinary incandescent lamp, it is difficult to believe that the delicate filament is not in some way immensely enlarged by the electric current or by the heat, but the experiment illustrated by the engraving shows that the size of the filament is unchanged, and proves that the effect is produced in the eye.

The experiment consists merely in holding a smoked or darkly colored glass between the eye and the lamp. The glass cuts off a large percentage of the light, and enables the eye to see the filament as it really is.

The effects of irradiation are different in different persons, and they are not always the same in the same person.

INTENSITY OF LIGHT.

It is estimated that 5,500 wax candles would be required to illuminate a surface twelve inches distant as strongly as it would be illuminated by the sun, while the light of a single candle at a distance of 126 inches would equal that of the full moon. The relative intensities of the light of the sun and moon are as 600,000 to 1.

Light from different sources can be compared and measured by the photometer, several forms of which have been devised. The usual way of determining the intensity of light from any source is to compare it with a standard of illumination, a "sperm candle weighing $\frac{1}{6}$ pound, and burning 120 grains an hour," being commonly used for this purpose. Thus it is that a gas flame or an electric lamp is rated at a certain candle power.

Owing to the divergence of luminous rays, the intensity of light decreases rapidly as the illuminated surface is removed from the source of light. This may be readily shown by holding a screen, say 12 inches square, half way between a lamp and the wall. The shadow of the screen on the wall will be 24 inches square. If the light falling on the screen be allowed to proceed to the wall, it will cover the area which was before in the shadow of the screen. This area being four times as large as that of the screen, it is seen that the light which was received on the screen must, when distributed upon a surface four times as great, be reduced in intensity to one-fourth of that falling on the screen. It is thus shown that the intensity of light is inversely as the square of the distance; that is, when the distance of the illuminated surface from the source of light is doubled, it receives one-fourth the amount of light; at three times the distance, one-ninth, and so on.

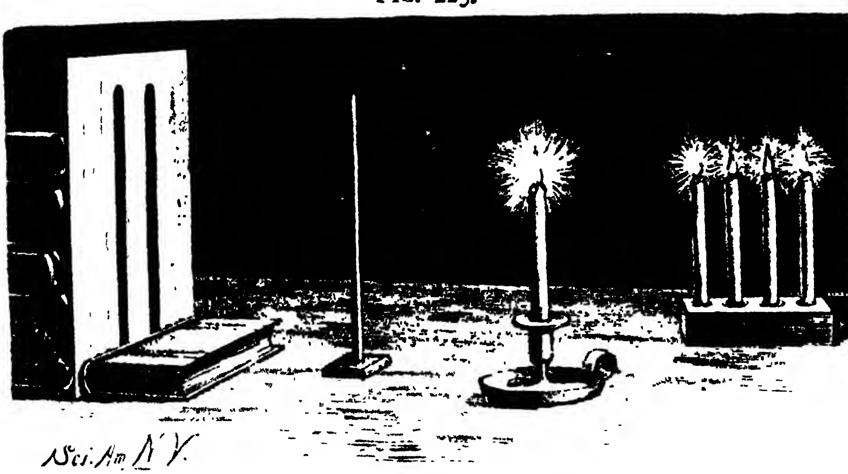
The law of inverse squares may be demonstrated by the extemporized photometer, shown in Fig. 225. In front of a white cardboard screen is supported an opaque rod. The sources of light to be compared are arranged so as to cast

separate shadows of the rod on the screen. If the sources of light when equally distant from the screen form shadows of the same depth, their illuminating power is the same.

When, however, the intensities of the two lights differ, the shadows will differ, and it will be necessary to remove the stronger light to a greater distance to secure shadows of equal depth.

In the experiment illustrated, the single candle being distant one yard from the screen, it is found that the group of four candles must be placed two yards from the screen

FIG. 225.



Photometer

to secure shadows of the same intensity. Nine candles would require removal to a distance of three feet, and so on. All the candles of the group must be in the same line in the direction of the rod. The eye is able to detect a difference of one-sixtieth in the values of the shadows, provided the lights be of the same color.

OPTICAL ILLUSIONS.

It is sometimes difficult, even for the practiced eye, to accurately estimate distances and dimensions, and to correctly appreciate forms. Very much depends upon the relation of the object viewed to surrounding objects. Two straight parallel lines of equal length would be appreciated by the eye in accordance with the facts, but when a light

line is drawn perpendicular to a heavy one of the same length, as in Fig. 226, the eye at once accords the greater length to the lighter line.

In the case of two like parallel lines joined at the ends in one case with outwardly convergent lines and in the other with outwardly divergent lines (Fig. 227), the apparent difference in the length of the lines is considerable.

It often happens in engineering drawing that a sectional

Fig. 226.

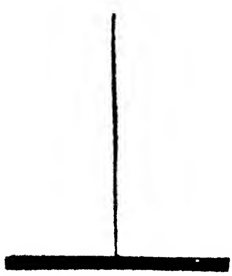
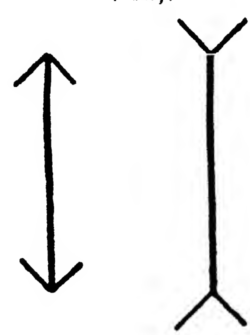


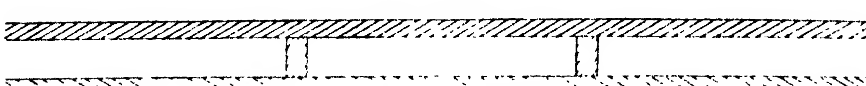
Fig. 227.



view will present some curious distortions, which give the drawing the appearance of being incorrect, but which in reality are only illusions. Fig. 228 is an example taken from such a drawing.

In Figs. 229 and 230 are shown examples of line combinations in which series of oppositely disposed oblique lines are joined to parallel lines. In Fig. 229 the latter appear to bend outwardly and in Fig. 230 they seem to bend inwardly;

Fig. 228.



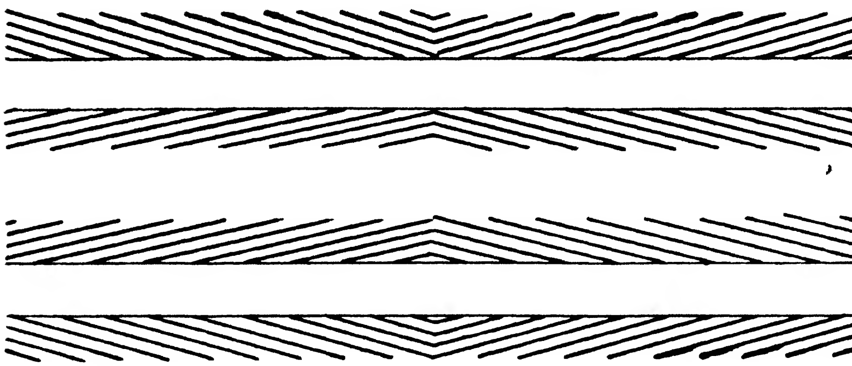
Illusion from Engineering Drawing.

but by looking at the diagrams lengthwise, or through partly closed eyes, the parallel lines appear as they really are.

A more marked example of the effects of oblique lines on a series of parallel lines is shown in Fig. 231.

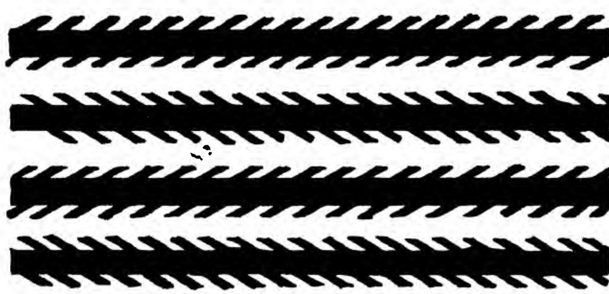
In Fig. 232 the single oblique line extending above the

FIGS. 229 AND 230.



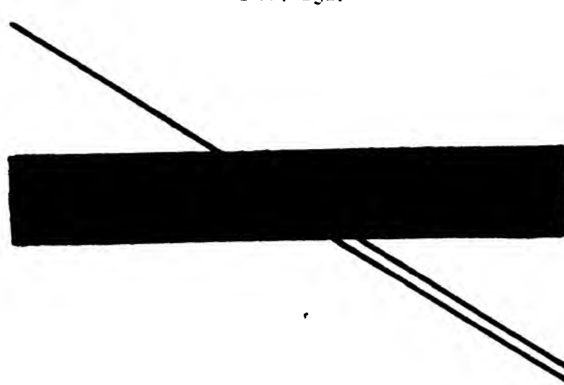
Apparent Deviation by Oblique Lines.

FIG. 231.



Parallel Lines appearing Alternately Convergent and Divergent.

FIG. 232.



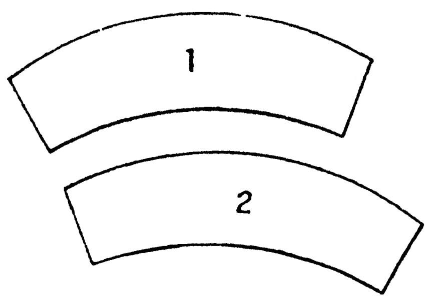
Apparent Displacement of a Single Oblique Line.

black bar appears to be a prolongation of the lower oblique line below the bar. That such is not the case may be shown by placing a card against the line above the bar or sighting it endwise. It will thus be shown that it is a prolongation of the upper of the two lines below the bar.

The curious optical illusions shown in Figs. 233 and 234 were published some time since in a French scientific journal.*

Fig. 233 represents two pieces of paper or cardboard cut into the shape of arcs of a circle. Which is the larger of the two? To this the answer will certainly be: "It is No. 2." But if No. 1 be placed under No. 2, the answer will be just the reverse. The fact is that both are exactly of the same size, as may be seen by measuring them, or by laying

FIG. 233



Curious Optical Illusion.

one upon top of the other. When the two figures are placed so close together that their edges touch, the illusion is still greater.

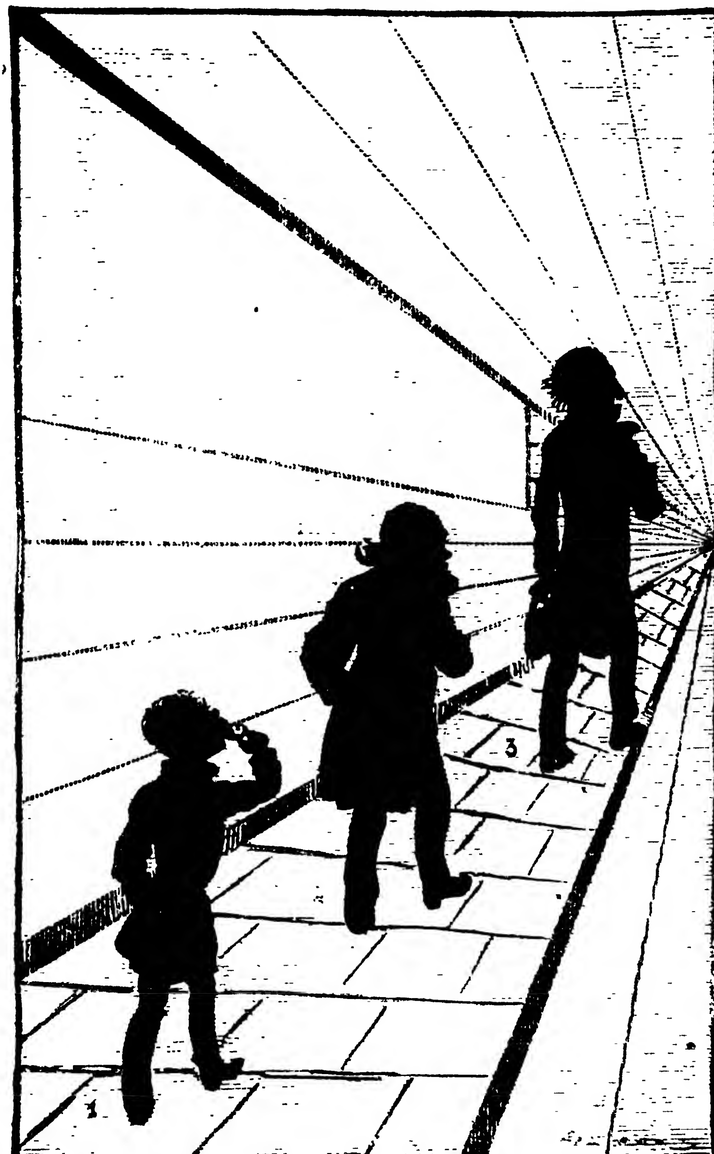
Which is the tallest of the three persons figured in the annexed engraving? If we trust our eyes, we shall certainly say it is No. 3. But if we take a pair of compasses and measure, we shall find that we have been deceived by an optical illusion. It is No. 1 that is the tallest, and it exceeds No. 3 by about 0·08 inch.

The explanation of the phenomenon is very simple. Placed in the middle of the well calculated vanishing lines the three silhouettes are not in perspective. Our eye is accustomed to see objects diminish in proportion to their

* *La Nature.*

distance, and, seeming to see No. 3 rise, concludes therefrom that it is really taller than the figures in the foreground.

FIG. 234.



An Optical Illusion.

The origin of the engraving is no less curious than the engraving itself. It serves as an advertisement for an English soap manufacturer, who prints his name in van-

ishing perspective between each of the decreasing lines, and places the cut thus formed in a large number of English and American newspapers.

Here is a row of letter S's and one of figure eights, taken at random.* At a casual inspection the reader might say the letters were symmetrically made—that is, the top and bottom lobes of the figures and letters the same size—though upon a close inspection he would either say that it was

S S S S S S S

8 8 8 8 8 8 8

doubtful whether any difference existed or he would notice the true relation that exists, the top lobe being the smaller.

Fig. 235.

Fig. 236.

Professor Thompson's Optical Illusion.

Let him, however, turn this page upside down, and the most cursory glance possible will show him their shapes, and the dissimilarity between the upper and lower halves will strike him with astonishment if he never tried the experiment before.

One of the most interesting of optical illusions is that devised by Prof. Silvanus P. Thompson. This is illustrated by Figs. 235, 236, and 237. The first of these figures is composed of a series of concentric rings about a twentieth of an inch wide and the same distance apart. If the

* Mr. G. Watmough Webster, in *British Journal of Photography*.

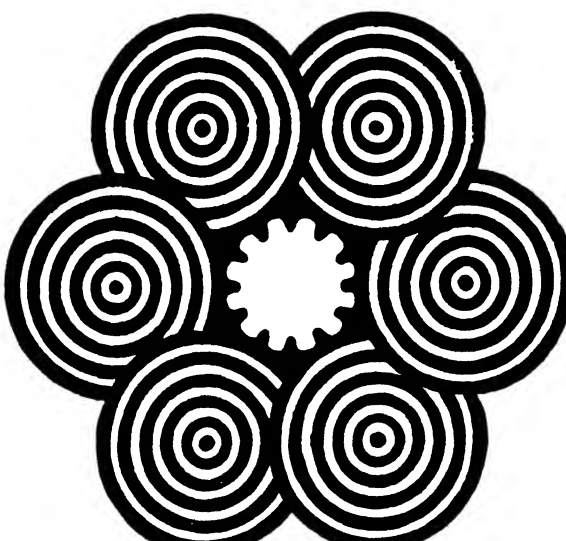
illustration is moved by hand in a small circle without rotating it, *i. e.*, if it is given the same motion that is required to rinse out a pail, the circle will revolve around its center in the same direction that the drawing moves.

A black circle (Fig. 236) having a number of equidistant internal teeth is provided for the second experiment, the drawing being moved in the manner above described, but in a contrary direction.

In Fig. 237 is shown a combination of the toothed and concentric circles.

By means of photographic transparencies Mr. Thompson has shown these figures on a screen on a large scale, and by moving the plates as before described, the figures on the screen were made to rotate.*

FIG. 237.



When viewed in a microscope under certain conditions, the minute markings of some of the diatoms appear as hexagons, while under other conditions, and with a first-class objective, they appear spherical.

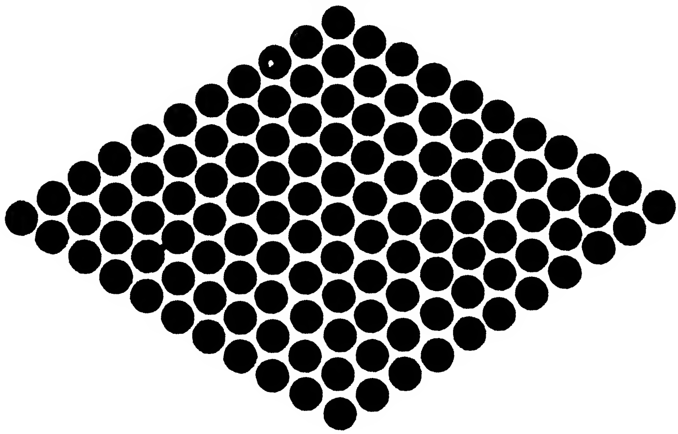
M. Nachet, the French microscopist, has published a

* A. O., on p. 133, vol. 41, *Scientific American*, furnishes an explanation of the phenomena of these circles.

curious optical illusion which, he thinks, accounts for the markings on the diatoms appearing as hexagons.

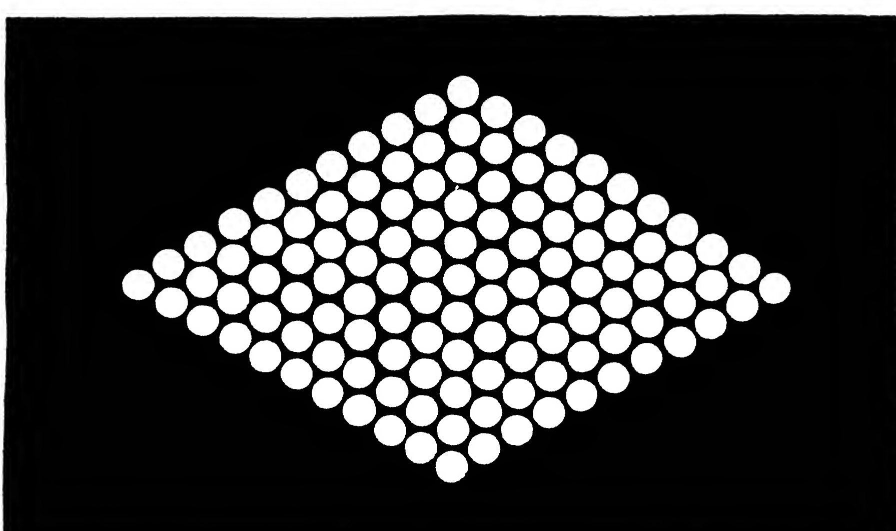
The circular spots (Fig. 238) are arranged as nearly as

FIG. 238.



possible like the markings on the diatom called *Pleurosigma angulatum*. If the figure is viewed through the eyelashes with the eyes partly closed, the circles will appear as hexagons.

FIG. 239.

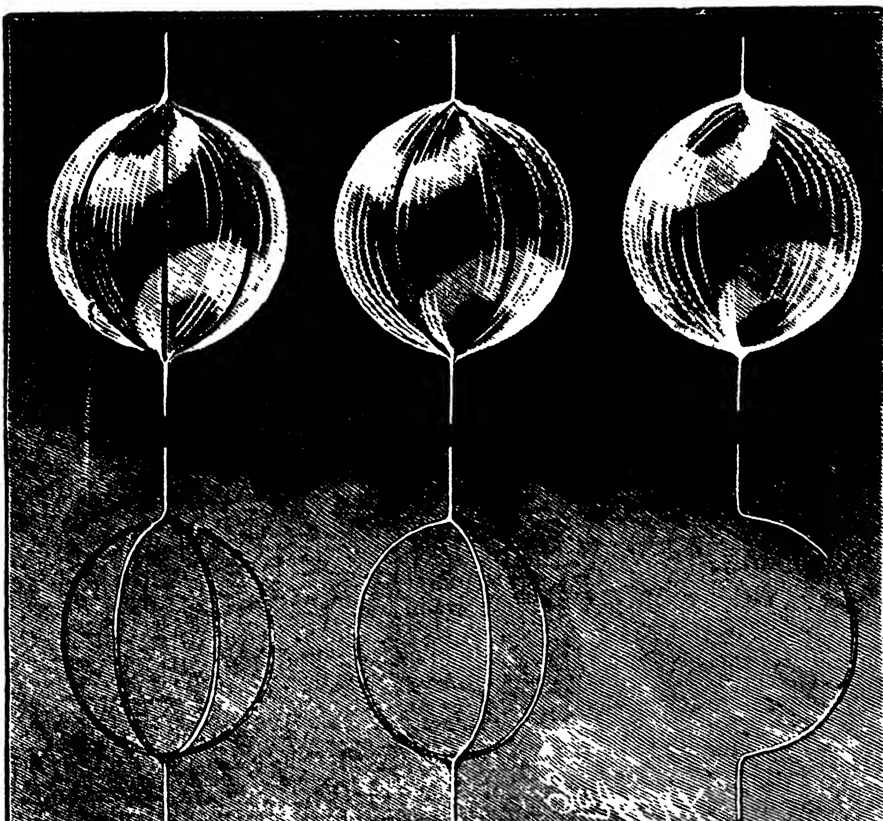


In Fig. 239 is shown a negative reproduction of Fig. 238, in which the spots are white on a black ground. When these figures are compared, the white spots, on account of

irradiation, appear much larger than the black ones, although they are of exactly the same size.

Fig. 240 illustrates an interesting illusion observed by Mr. J. Rapieff, the well known electrician. The apparatus consists of semicircular and circular wire loops, provided with axles, by which they may be twirled between the thumbs and fingers. The lower row of figures shows some of the

FIG. 240.



Rapieff's Optical Illusion.

loops used in the experiment, while the upper figures represent the effects produced. The wire has a polished surface. When the single semicircular loop is twirled, the only effect is to produce a gauzy glimmer of spherical form, as shown in the upper right hand figure. When three of the loops are joined together, each extending from the other at an angle of 120°, the figure produced is similar to that already

described, but with two perfectly distinct curved black lines extending from one axle to the other, as shown in the upper central figure. When four loops are joined at right angles to each other, three jet black lines are shown, as indicated in the upper left hand figure. A circular loop shows a single black line.

This curious effect is produced by holding the apparatus so that the light is reflected as much as possible from the inner surface of the wire. The result is due to the eclipsing of the bright surface by the shaded portion of the upper loop as it passes between the eye and the lower loop. The whole of the loop is not eclipsed at the same instant, but persistence of vision causes the entire eclipse to be seen at once.

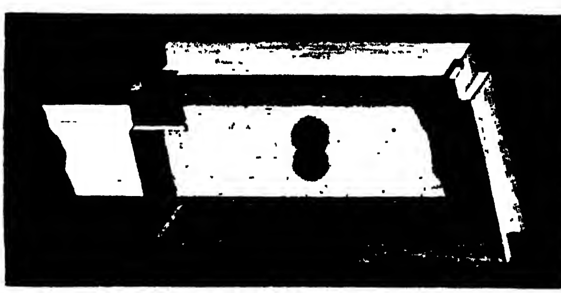
Success in this experiment depends upon holding the loops in the right position relative to the light, as well as the provision of the proper background. The loops should be held over a dark ground, with the axles parallel with the plane of vision.

CHAPTER XII.

POLARIZED LIGHT.

Glass, like all uncrystallized bodies, is said to be single refracting, because it diverts the ray in one direction only. By placing a rhomb of Iceland spar over a small black spot formed on a piece of white paper, two images of the spot appear, showing that the beam of light has been split up into two rays, one of which is called the ordinary ray, the other the extraordinary ray. As the rhomb is turned, the extraordinary ray moves around the ordi-

FIG. 241.



Iceland Spar.

nary one, and the image of the spot produced by the extraordinary ray appears nearer to the observer than the spot itself. This property of splitting the ray transmitted through the crystal, which was first noticed and commented on by Erasmus Bartholinias, in 1669, is known as double refraction. It is possessed by many crystalline bodies in a greater or less degree. Both rays emerging from the spar have acquired peculiar properties.

Newton, after investigating the properties acquired by light in its passage through the spar, concluded that the particles had acquired characteristics analogous to those of magnetized bodies, that is, they had become two-sided, and were, in fact, polarized.

Light, in the state of two-sidedness as observed by Newton, is still known as polarized light. By inserting the double refracting crystal known as tourmaline between the eye and the rhomb of spar, and turning it, the ordinary and extraordinary rays will be extinguished and will reappear in alternation. All vibrations, except those executed parallel with the axis of the tourmaline, are quenched. A Nicol prism (to be described later on) will do the same thing. When the Nicol is turned, the black spots seen by the two rays become alternately visible and invisible. One-quarter of a revolution of the prism is sufficient to extinguish one ray, and bring the other out; and a further turning of the prism through another quarter of a revolution

FIG. 242

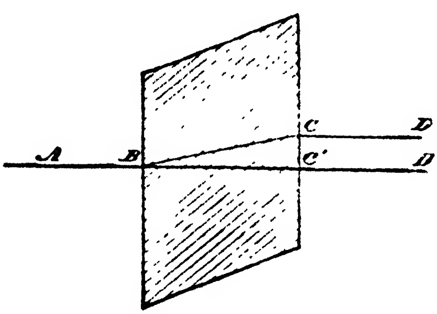
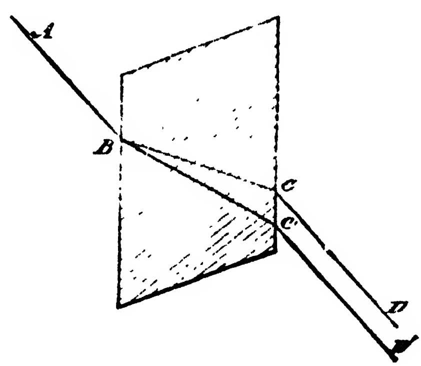


FIG. 243.



Course of Light through Iceland Spar.

reproduces the extinguished spot and effaces the visible one. This experiment shows that the vibrations of the two rays are in planes at right angles to each other. A beam of light in which all of the transverse vibrations are parallel with a single plane is plane-polarized. Both of the beams emerging from the spar are therefore plane-polarized, but in different planes.

The course of the light through the rhomb of Iceland spar when the incident ray is perpendicular to one of the faces of the crystal is shown in Fig. 242. The ordinary ray, A, passes straight through the crystal on the line, A C′, while the extraordinary ray is bent away from the ordinary ray, on the line, B C.

When the incident ray enters the side of the rhomb at an angle (as shown in Fig. 243), the ordinary ray follows the law of refraction, and the extraordinary ray is bent away from the ordinary ray, as in the other case.

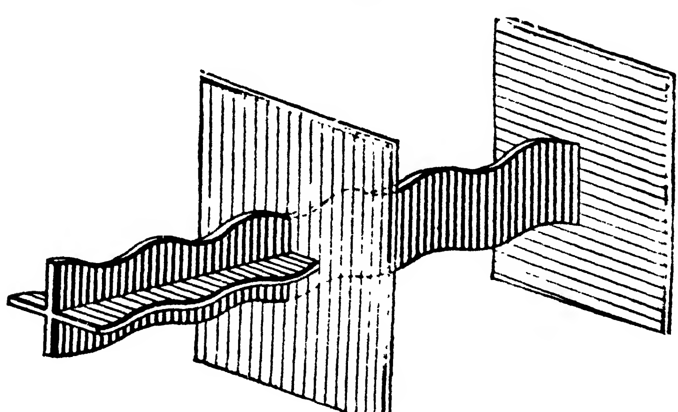
FIG. 244

Nicol Prism.

The most perfect instrument for polarizing light and analyzing it after its polarization is the Nicol prism, made from a rhomb of Iceland spar, and named after its inventor. In this prism, the ordinary ray is disposed of, and the extraordinary ray alone is used.

The prism which is shown in Fig. 244 consists of a rhomb of Iceland spar, divided through its axis on the line, D D, with its ends cut off at right angles to this line. The two halves of the prism are cemented together by Canada balsam, whose index is between that of the two indices of the spar, so that the ordinary ray, B C′, meets the film of balsam at an angle which is sufficiently oblique to secure the reflection of this ray to one side, where it is lost, while the extraordinary ray, B C, passes through the balsam, and onward through the other half of the prism perfectly polarized.

FIG. 245.



Action of Tourmaline Crystals.

To observe the effects of polarization, an analyzer is required. Anything that will act as a polarizer will also serve

as an analyzer, and since the Nicol prism is unsurpassed as a polarizer, it will answer equally well for an analyzer.

Perhaps the action of polarized light cannot be better illustrated than by a representation of a hypothetical beam of light and two tourmaline plates (Fig. 245). Here is shown the beam of light with vibrations traversing the path of the beam in two directions. On reaching the first tourmaline plate, those vibrations which are parallel with the axis of the tourmaline crystal (represented by the parallel lines) are readily transmitted, but all the vibrations in any other direction are extinguished. The beam now polarized passes on to the second tourmaline plate, and the axis of the crystal being arranged at right angles with the plane of vibration, it is extinguished; but if the axis of the

FIG. 246

FIG. 247

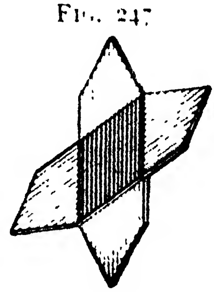
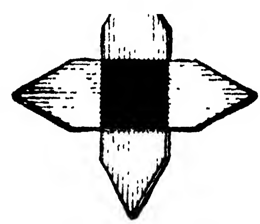


FIG. 248.



Tourmaline Plates

second tourmaline is parallel with the plane of vibration, the light will pass through.

If the axes of the tourmalines are arranged at an angle of 45° with each other, the light is only partly extinguished.

These effects of the two tourmaline plates are illustrated by the annexed diagrams, Fig. 246 showing the crystals with their axes arranged parallel with each other, Fig. 247 showing them arranged at an angle of 45°, and Fig. 248 shows them crossed or arranged at right angles with each other, exhibiting a complete extinction of the ray at the intersection of the crystals.

If, now, when the polarizer and analyzer cross, a double refracting crystal be inserted between them, the light passing the polarizer will be made to vibrate in a different plane, and will therefore prevent the complete extinction of the beam by the analyzer.

Besides those means of polarizing light already described, there are others which should be examined. Light is polarized by reflection at the proper angle from almost every object; glass, water, wood, the floating dust of the air, all under certain conditions will polarize light.

That the light beam becomes polarized may be readily ascertained by receiving it through a double-refracting body and an analyzer.

FIG. 249.

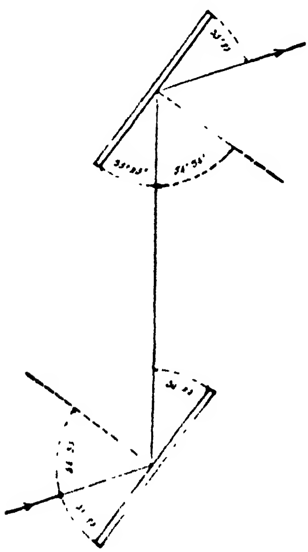
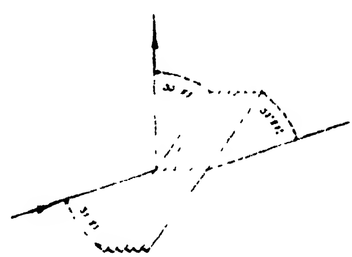


FIG. 250.



Polarization by Reflection and Refraction.

Two plates of unsilvered glass, receiving and reflecting light, as indicated in Fig. 249, act respectively as polarizer and analyzer.

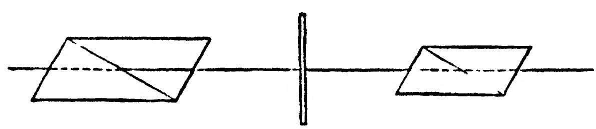
For every substance there is an angle at which the polarization is at a maximum. For common window glass the angle the ray must make with the normal is 54° 35′. This is called the polarizing angle. It depends upon the index of refraction of the glass, and is such that the reflected and transmitted rays are at right angles to each other.

Balfour Stewart explains polarization by reflection as follows:

"It is imagined that in the reflected ray the vibra-

tions are all in a direction perpendicular to the plane of reflection, so that the portion of the incident ray consisting of vibrations in the plane of reflection has not been reflected at all. If, therefore, we allow an ordinary ray of light (Fig. 249) first to be reflected from a plate of glass, at the polarizing angle, and if the reflected ray be again made to impinge upon another surface of glass at the same angle, the latter will then be the analyzer, and if its plane be parallel to the polarizer, as in the figure, the light will be again reflected in the direction indicated by the arrow. If the analyzer be turned round the first reflected ray as an axis, until its plane is at right angles to the polarizer, it will be found that the light is no longer reflected. For the reflected ray consists entirely of vibrations perpen-

FIG. 251.



Arrangement of Polarizer, Analyzer, and Object to be Examined.

dicular to the first plane of incidence. But vibrations perpendicular to the first plane of incidence will be in the second plane of incidence, which is at right angles to the first, and therefore they will not be reflected from the second surface."

A series of thin plates (Fig. 250), at the proper angle, polarizes light in a marked degree. These plates will also act in a similar manner when the light is transmitted through them, a part of the light in each of these cases being reflected and a part transmitted, both the reflected and transmitted beams being polarized, but in planes at right angles to each other. A single black glass plate is a good polarizer, but a bundle of glass plates backed with black is perhaps better. The arrangement of the polarizing and analyzing prisms with reference to the object to be examined is shown in Fig. 251.

The beam of polarized light may be apparently depolarized by a body which will produce no color, but will simply

render the field bright when the polarizer and analyzer are crossed, as shown by the insertion of a rather thick piece of mica between the polarizer and analyzer.

By placing thinner pieces of mica in the same position, various colors are produced. When the polarized beam encounters the thin mica, it is resolved into two others at right angles to each other, the waves of one being retarded with reference to the other; but as long as these rays vibrate at right angles to each other, they cannot interfere. The analyzer reduces these vibrations to the same plane, and renders visible the effects of interference due to the retardation of the waves of one part of the beam. The thick plate of mica gives no color, because the different colors were superposed and blended together, forming white light.

In a slice of Iceland spar cut at right angles to the axis of the crystal, the ray is not divided as it is when the light passes in any other direction through the crystal, and if the slice be placed in a parallel beam of polarized light, no marked effect is produced; but when the beam is rendered convergent, by a lens interposed between the polarizer and the crystal, beautiful interference phenomena are developed.

When the polarizer and analyzer are crossed, a system of colored rings intersected by a black cross appears.

The arms of the cross are parallel with the planes of the polarizer and analyzer. On these lines no light can pass, but between them the colors of the rings increase in intensity toward the middle of the quadrants inclosed by the arms where the interference is most marked. Turning the polarizer or analyzer causes complementary colors to change places, and brings out a white cross instead of the dark one.

SIMPLE EXPERIMENTS IN POLARIZED LIGHT.

It is ever a source of pleasure to the student of science to be able to explore an unfamiliar realm by means of commonplace and readily accessible things, which, if not already possessed, may be had almost for the asking.

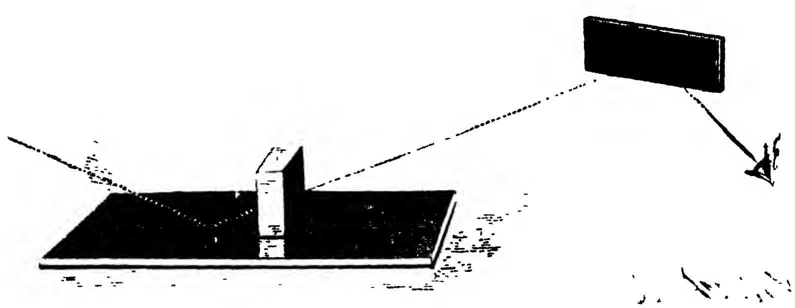
The e is scarcely a branch of scientific research more prolific in the development of expensive apparatus than that of light, yet there is nothing in the domain of physics capable

of being better illustrated by apparatus of the most simple and inexpensive character. The subject of polarized light, as intricate and difficult as it may at first appear, may be illustrated by apparatus costing less than a dime, in a manner that can but excite the wonder and admiration of one inexperienced in this direction.

A small piece of window glass and a black-covered book constitute the apparatus for beginning the study of this interesting subject, and with a glass bottle stopper, a glass paper weight, or a piece of mica, the effects of polarized light may at once be shown.

The book is placed horizontally near a source of light,

FIG. 252



Polarization by Reflection from Blackened Glass.

such as a window or a lamp, so that a broad beam of light will fall obliquely on it, and upon the book is placed the object to be examined, which may be either of those named.

Now, by viewing the reflected image of the object in the piece of window glass, with the glass arranged at the proper angle, it is probable that colors will be seen in the object. If no colors appear, it is due to one of three causes: either the object is incapable of depolarizing the light polarized by reflection from the book cover, or it is too thick or too thin to produce interference phenomena, or the eye of the observer and the glass employed for the analyzer are not in a correct position relative to the object and the polarizer (the book cover).

The glass, if thoroughly annealed, will produce no effect on the polarized beam, but most thick pieces of glass, such

as paper weights, ink stands, heavy glass bottle stoppers, and the like, are either unannealed or only partly annealed, and are thus under permanent strain, which is readily indi-

FIG. 253.

Analyzation by Bundle of Glass Plates—Strained Glass.

cated by their action on polarized light. A plate of mica of suitable thickness exhibits bright colors when examined by polarized light, particularly when the plate is either bowed or inclined.

To render the polariscope thus described more efficient, a plate of glass may be placed on the book, when the superior reflecting surface will at once make itself manifest in the increased brightness of the colors and improved definition of the object. A still greater improvement may be made by blacking one side of each glass with asphaltum varnish or any other convenient black varnish or paint, using in the experiments the unblackened surfaces, as shown in Fig. 252.

The angle which the incident light beam should make with the polarizer or horizontal blackened plate is 35 25, and the polarized beam should strike the analyzing plate at the same angle to secure the maximum effects; but it is unnecessary to measure the angles, as they may be easily determined by the appearance of the object.

With the two plates of blackened glass much may be learned with regard to the properties of polarized light. Plates of mica of various thicknesses and forms, inclined at various angles, bowed and turned in their own planes, pieces of quartz, bodies of glass such as those already mentioned, and odd-shaped pieces of unannealed glass, such as may be picked up at glass works, are easily secured objects. Brazilian pebble spectacle lenses often show gorgeous colors when turned at different angles in the beam of polarized light.

The best position for the polarizing plate is near a window, with the broad light of the clear sky shining upon it.

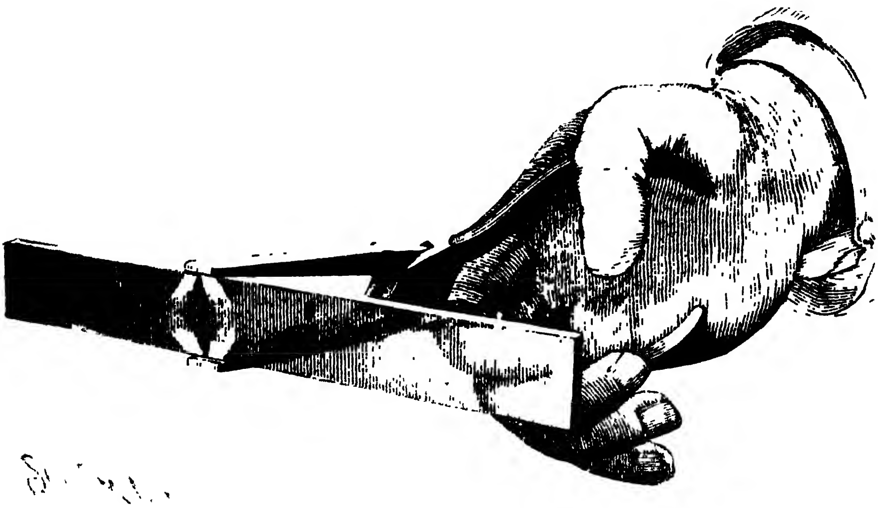
By turning the analyzing plate on the axis of the light beam, some curious effects may be observed. When the plates are at right angles with each other, the polarized beam will be nearly quenched,* and when they are parallel with each other, the reflection of the sky will be quite bright.

The employment of a blackened glass reflector for an analyzer is attended with some difficulty, on account of the necessity of changing the position of the eye for each new

* With black glass reflectors employed as polarizer and analyzer, the extinction of the light is not quite complete, even when they are arranged accurately at the polarizing angle.

position of the analyzer. A bundle of six or eight plates of ordinary glass is more convenient, but not quite so efficient.

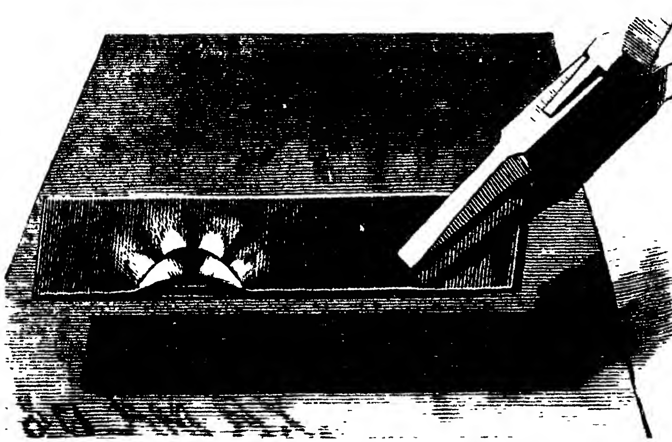
FIG. 254.



Glass Strained by Pressure.

These plates will be used as shown in Fig. 253, the light passing through them to the eye instead of being reflected.

FIG. 255



Glass Strained by Heat.

The plates may be turned at any angle without changing the position of the eye.

The most perfect analyzer, however, is the Nicol prism. A very small one will answer perfectly for this class of experiments, and is not expensive. But to return to our experiments; when the analyzer and polarizer are crossed and the field is dark, if a few pieces of mica of various thicknesses and shapes are held between the analyzer and the black glass plate, and bowed and inclined at different angles, a great variety of tints will be observed, and if held in one position while the analyzer is turned, another effect will be noticed.

Among the objects which may be examined in this way are the paper weights, stoppers, and other thick, partly annealed pieces of glass, a piece of glass held edgewise in a hand vise or pair of pliers, and put under compression, as shown in Fig. 254. A piece of glass held edgewise for a moment in a small gas or candle flame, and then placed in the polarized beam, shows the strain by a light figure, like that represented in Fig. 255, or it may assume other forms, according to circumstances. As the glass cools, the figure fades away.

Small glass squares and triangular and diamond-shaped plates, about three-quarter inch across, suspended by a fine wire in the flame of a Bunsen burner or alcohol lamp until their corners begin to fuse, and then cooled in air, become permanently strained, and exhibit symmetrical figures formed of dark and light spaces, but show little color on account of their thinness. By superposing several such plates, color effects may be seen.

The beautiful *verre trempe*, or strained glass blöcks, a few examples of which are represented at *a*, *b*, *c*, *d*, in Fig. 253, are similar in character to what has just been described. They vary in thickness from one-fourth inch to one-half inch, and even thicker. They are expensive objects, but exceedingly beautiful and interesting.

In Fig. 256 is shown a method of polarizing and analyzing with a single bundle of plates. It is, in principle, a Norremberg doubler. The light strikes the under surface of the bundle of plates at the polarizing angle, and is reflected downward in a polarized state, passing through the object

which rests upon the horizontal silvered mirror. It is then reflected back through the object, and passes through the bundle of plates to the eye of the observer; the plates, as before stated, serving to analyze the polarized beam.

FIG 256.

FIG 257.

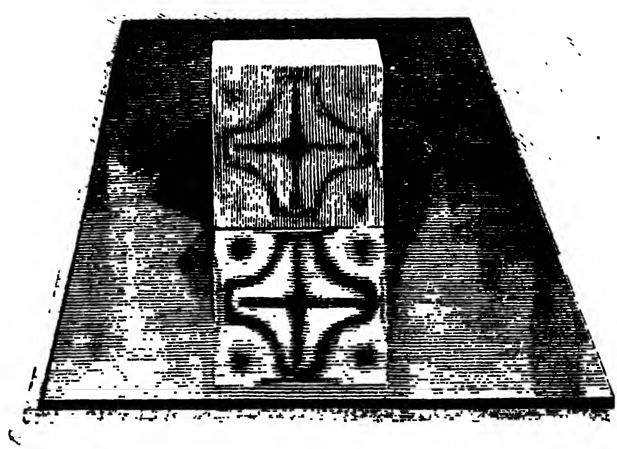
Simple Form of Norremberg Doubler.

A Norremberg doubler, which answers a good purpose, may be made by leaning a clear plate of glass upon the edge of a book, over a piece of ordinary looking glass, and employing a bundle of glass plates as an analyzer, as shown in

Fig. 257. Here the polarization is effected by the single plate of glass, and the analyzation by the bundle of plates held in the fingers. Equipped with this instrument, the student of polarized light may proceed a long way with his investigations.

In this instrument the objects to be examined are laid upon the horizontal mirror, and the inclined plate is arranged with reference to the light so that it will reflect the broad light of the sky downward. The position of the

FIG. 258.



Double Polarization with Single Glass Plate.

single plate and bundle of plates may be varied to secure the best effects.

In Fig. 258 is shown an arrangement by which the object and the blackened glass both act simultaneously as polarizer and analyzer. By placing a specimen of strained glass edgewise on the blackened glass, as shown in the engraving, the light, striking the strained glass at about the polarizing angle, is reflected from the back surface of the glass and partly polarized. The beam thus polarized is reflected downward obliquely, and at the same time depolarized by the

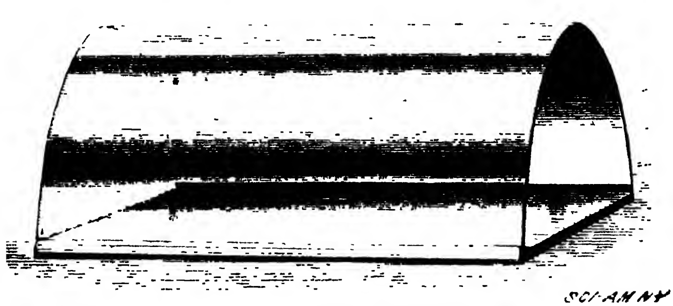
strained body of the glass; it is reflected upward to the eye and analyzed by the blackened glass mirror, thus producing an image which is apparently below the surface of the mirror. The image seen in the strained glass itself is produced by the reverse of what has just been described. The light is polarized and reflected by the black glass mirror, and passes through to the back surface of the strained glass, which reflects it back through the body of the glass: the glass then acts as both object and analyzer.

When the polarizer, analyzer, and object are each movable, different effects will be produced by rotating any of them. As a means of exhibiting complementary colors, nothing can excel the polariscope, since the colors produced in the successive changes resulting from turning the analyzer or polarizer are necessarily complementary to each other.

MICA OBJECTS FOR THE POLARISCOPE.

A few simple objects easily prepared from mica are here shown. The material is of course procurable everywhere, and it requires little more than a glance at the engravings to enable any one to prepare the objects. Doubtless many

FIG. 259



Mica Semi-Cylinder.

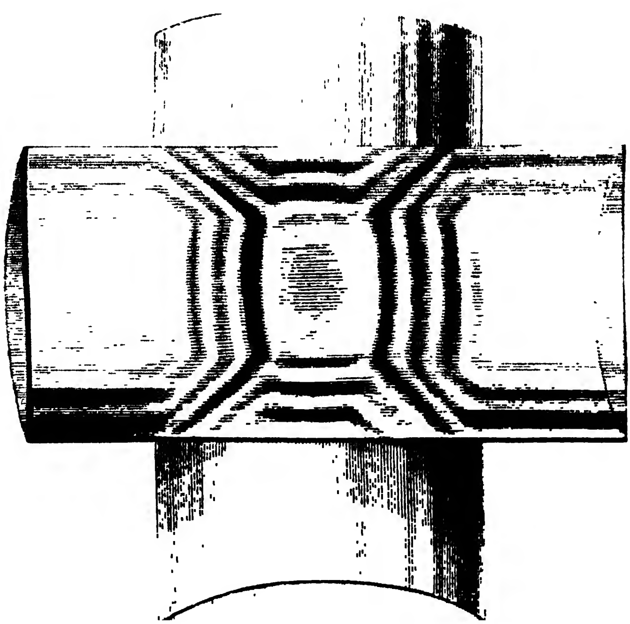
other forms than those illustrated will suggest themselves to the student.

The simplest form is shown in Fig. 259. It consists of a thin plate of mica bowed into approximately semi-cylindrical form, and secured by its edges to a plate of glass by means of narrow strips of gummed paper. The size is im-

material; the glass plate may be 1½ inches wide by 3 inches long. This object exhibits fine bands of prismatic color when viewed in the polariscope. Two such semi-cylinders, when crossed, exhibit the intricate figure shown in Fig. 260, with all the splendid colors of the spectrum.

The object shown in Fig. 261 is formed of a disk of mica having a sector cut out and the radial edges overlapped, forming a low cone. The overlapping edges are best fastened together by small tin clips inserted in holes in the mica and bent downward on opposite sides. The clips are not noticeable, and are efficient in holding the edges together. Cement will not answer the purpose, as it adheres to the surface only, and it must be remembered that mica splits almost indefinitely.

FIG. 260.

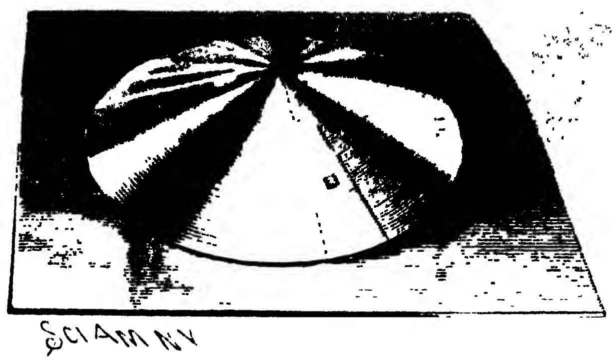


Mica Semi-Cylinders Crossed.

The cone thus made has the appearance in the polariscope of a huge circular crystal of salicine. The colors of the cone may be heightened by mounting it on a sheet of

mica, as shown in the engraving. The cone is first placed in the polariscope, with the polarizer and analyzer crossed, and turned until it appears brightest, when the lower edge is marked. The mica sheet is then placed in the polariscope,

FIG. 261

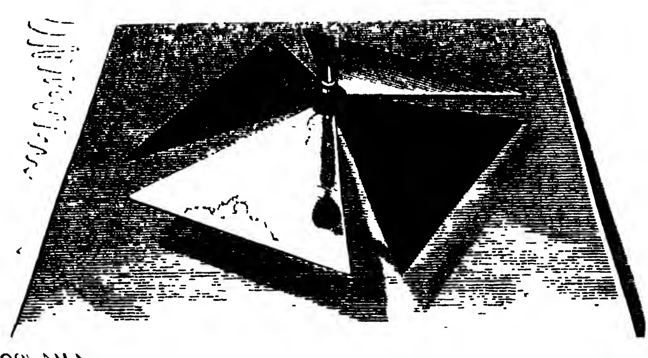


Mica Cone.

and turned and marked in a similar way. The cone is then cemented by its edges to the sheet, the marked edges of both members being arranged in the same direction.

The Maltese cross shown in Fig. 262 is revoluble. The

FIG. 262.



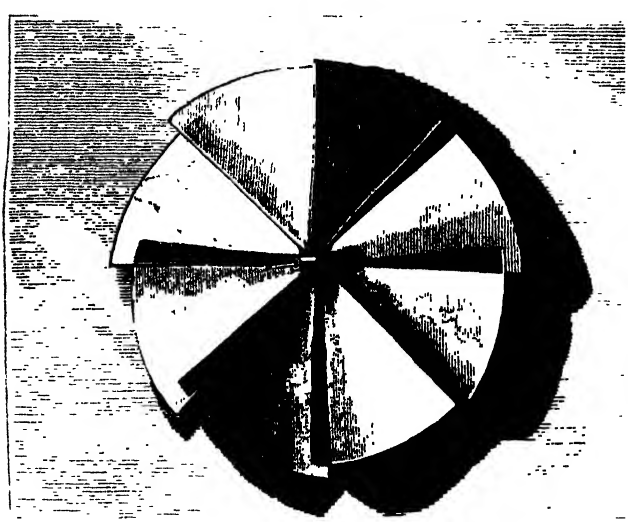
Maltese Cross.

first step toward the preparation of this object is to secure a pin head downward on a square of glass with sealing wax or other cement. A small paper tube which will fit the pin loosely is then made, and a little head of sealing wax is formed around the tube near one end. A piece of mica is

selected which exhibits fine colors in the polariscope, and four equilateral triangles are cut from it, either with their corresponding sides cut upon the same base line, or with one side of each cut from one side of a square, or they may be cut and mounted haphazard.

To the apex of the angle designed for attachment to the paper tube a small drop of sealing wax is applied, and with the tube on the pin the first triangle is attached by holding it in the required position by means of a pair of tweezers, and then fusing the wax on the mica and that on the tube

FIG. 263



Mica Wheel.

simultaneously by means of a small heated wire, such as a knitting kneedle.

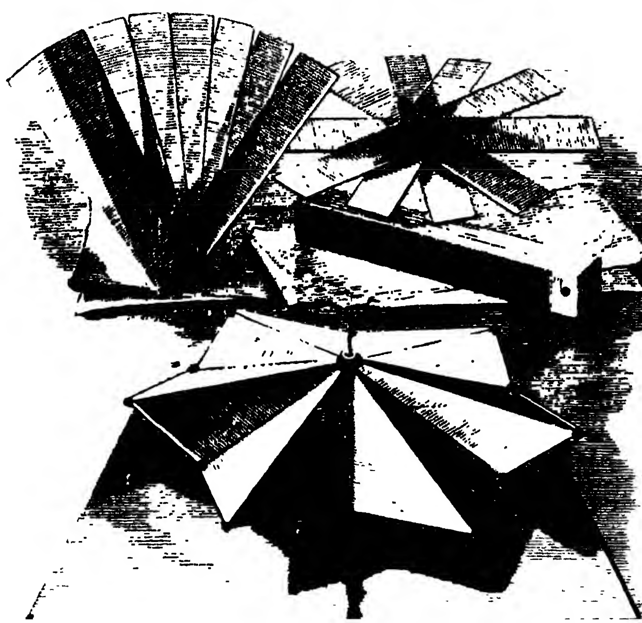
The other members are placed and secured in a similar way, care being taken to arrange the triangles symmetrically, and at a slight angle with the plane of rotation of the object, as shown in the engraving.

The wheel shown in Fig. 263 and the star shown in Fig. 264 are prepared in a similar way. The sections of the wheel are cut from a circular piece of mica, and cemented in place on the paper tube after the fashion of a propeller

wheel or wind wheel. Each ray of the star is made of two scalene triangles of mica oppositely arranged with respect to each other, and inclined in opposite directions, the longer and shorter sides of adjacent triangles being fastened at the periphery of the star by a minute drop of sealing wax.

In Fig. 264, beside the star are shown two somewhat similar objects, formed of strips of mica, pivoted together on a small rivet, one object having the pivot in the center

FIG. 264.



Star, Fan, and Crossed Bars of Mica.

of the strips, the other having it at the end, giving the object an appearance similar to that of a folding fan.

Any of these objects may be viewed by means of the black glass polarizer in connection with either of the forms of analyzer already described or in the simple form of Norremberg doubler. These objects are also very satisfactory when projected on the screen.

POLARISCOPES.

One of the simplest and best instruments for a certain class of investigations in polarized light is the Norremberg

doubler, named after its inventor, and shown in a very simple form in Fig. 265.

To one edge of a wooden base, 6 in. square and three-fourths of an inch thick, is secured a vertical standard, 1 in. square and about 15 in. high, and to the top of the standard is attached an arm extending over the center of the base, and apertured to receive the short tube containing the analyzing prism or bundle of glass plates. The tube may be made of paper, hard wood, or metal, and it should be fitted with a shoulder, so that it will turn readily in the aperture of the arm. To the standard below the arm is fitted a stage formed of a thin piece of wood centrally apertured and blackened.

The stage is notched to receive the standard, and is attached to a short vertical bar 1 in. wide. A clip of wood extending across the back of the bar, and two small clips secured to the sides of the short vertical bar, bear with sufficient friction on the standard to hold the stage in any desired position.

About 6 in. above the base a grooved wooden strip is pivoted to the standard, by means of a common wood-screw passing loosely through the grooved strip and tightly through the standard. A wooden knob is turned on the end of the screw, and serves as a nut to bind the grooved strip in any desired position. The strip, screw, and knob are shown in detail at 2, Fig. 265.

Into the groove of the strip is wedged or cemented a plate of glass, 4 by 9 in. A fine piece of ordinary window glass will answer, but plate glass is preferable.

Upon the base is laid a square of ordinary looking glass, or, better, a piece of plate mirror.

The tube, shown in detail partly in section at 3, is provided with an inner tube of pasteboard or wood, divided obliquely at an angle of 35° 25′ with the axis of the tube, and upon the oblique end of one-half of the tube are placed twelve or fifteen well cleaned elliptical microscope cover glasses, which are held in place by the other half of the divided tube. This bundle of glass plates, if of good quality and well cleaned, forms a very good analyzer; but

instead of this, if it can be afforded, a small Nicol prism should be secured and mounted in a centrally apertured cork, the latter being inserted in the analyzer tube, as shown at 4.

The object to be examined may be laid either on the stage or on the mirror below. If viewed on the stage, the usual effects will be observed; but if laid on the mirror, it is traversed twice by the light, once by the incident beam and once by the reflected beam. This is particularly noticeable in thin films of mica and selenite, and it serves as an excellent means for selecting eighth and quarter wave plates, which are useful in the study of circular and elliptical polarization.*

It is quite difficult to produce a perfectly uniform thin film of selenite, owing to the brittleness of the material. For this reason mica is generally used, as it possesses considerable flexibility and toughness. The common method of cleaving off thin films of mica is to split off a moderately thin plate and then separate the laminæ at one of the corners by bending it between the thumb and fingers. A medium sized sewing needle secured point outward in a slender handle is probably the best instrument for teasing the laminæ apart; but after the separation begins, the thin end of the ivory handle of an ink eraser seems to serve the purpose exceedingly well.

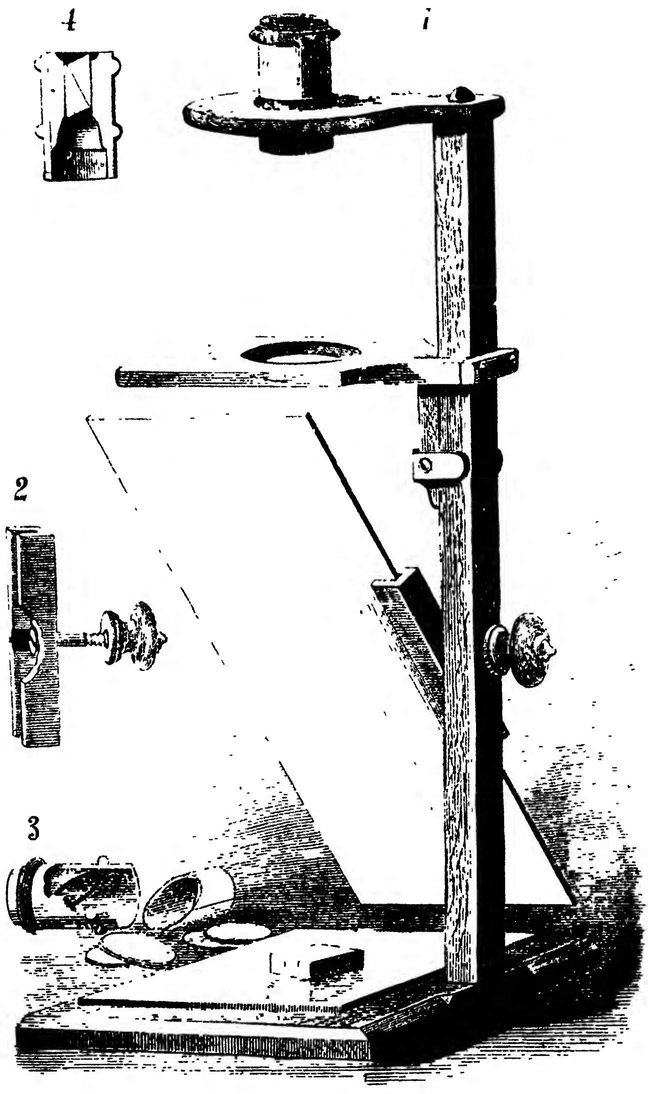
A score or so of plates are split, and examined one by one in the Norremberg doubler, by laying them on the mirror and turning them in their own planes, while the polarizer and analyzer are crossed. Should the plates exhibit any unevenness under the test, they should be at once rejected. Such as exhibit an even tint should be preserved carefully, and examined further to determine which, if any,

* The writer intends to deal sparingly with the theoretical part of this subject, especially the portion relating to circular and elliptical polarization, it having been treated extensively in many physical works and in books especially devoted to light and optics. Daniel's "Physics," prominent among works of its class, "Light," by Lewis Wright, and "Polarization of Light," by William Spottiswoode, are excellent books, bearing directly on the subject. The writer knows of no better means of securing a good knowledge of polarized light than by reading these three books.

possess the required qualities. Not every piece of mica will split evenly, therefore it may be necessary to make several trials before success is attained.

Should the film, when placed on the stage, exhibit a dull

FIG. 265.



Simple Norremberg Doubler.

plum color, slightly inclined toward red, when the polarizer and analyzer are parallel, it produces a difference of phase of half a wave length, and is called a half wave film. As

a matter of course, if two films of like thickness, superposed and arranged with their axes in the same direction, produce the same color under the same circumstances, they are one-fourth wave films; and if a pair of films exhibit the same color when similarly arranged on the mirror of the doubler, they may be regarded as eighth wave films, as the polarized beam passes twice through the film to produce the same tint. These films should be carefully mounted between glass plates, either dry or in benzole balsam, the latter being preferable.

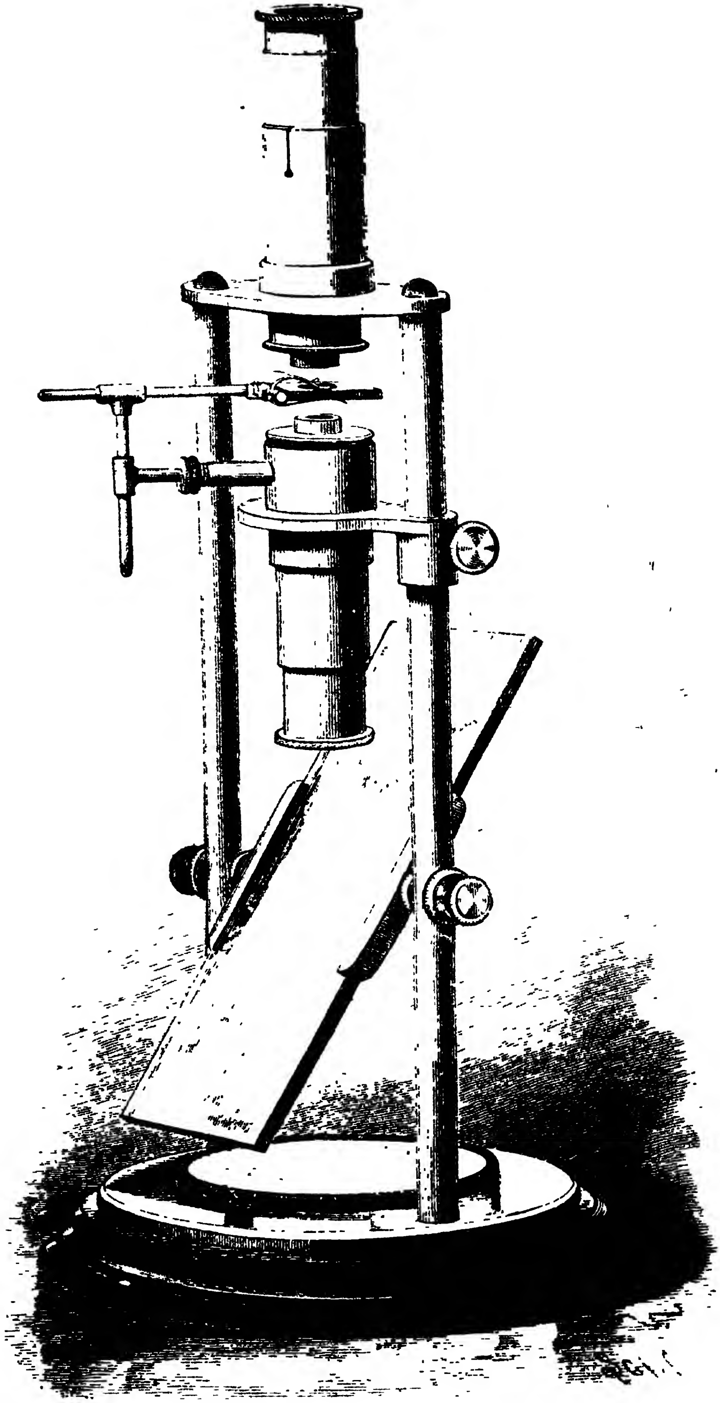
The practical application of the eighth and quarter wave films will be treated further on. Beautiful and instructive designs made from thin films are described and illustrated in Wright's "Light," to which reference has been made.

The only simple device for exhibiting the rings and brushes of wide-angled crystals is the tourmaline tongs (Fig. 274), of the kind commonly employed by opticians for testing spectacle lenses; but the dark color of ordinary tourmaline renders a polariscope of this kind objectionable.

A system of lenses devised by Norremberg, and improved by Hoffman, is at present employed for observing the phenomena of wide-angled crystals; but it is a matter of some difficulty to secure exactly such lenses as are required for the apparatus as constructed by Hoffman. Very good results, however, may be obtained by the employment of lenses designed for other purposes. Reference is made to the hemispherical condensing lenses used by microscopists, and ordinary meniscus (periscopic) spectacle lenses. Six lenses in all are required. The converging and collecting systems are exactly alike, but they are oppositely arranged with respect to each other. In the present case the two systems are adapted to a Norremberg doubler, Fig. 266, substantially like that described in a former part of this article, the main difference being that the instrument now illustrated is made principally of metal.

The tube of the upper system of lenses is prolonged upward beyond the upper lens, Fig. 267, to receive a Nicol prism, E, or other analyzer, which is mounted in a short inner tube arranged to revolve in the outer tube.

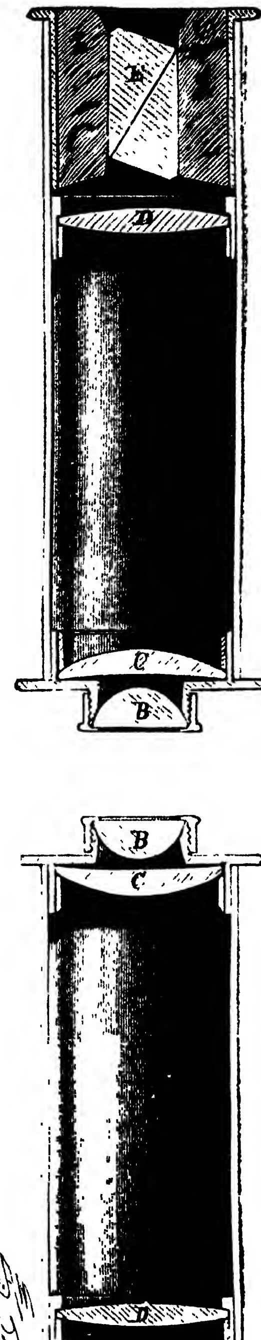
FIG. 206.



Polariscope for exhibiting Wide angled Crystals.

The lower system of lenses is contained by a tube fitted to the stage of the doubler. The arrangement of the lenses and analyzer is shown in Fig. 267. The two systems of lenses being alike, a description of one will answer for both. The object, A, to be observed is held between the adjacent ends of the two tubes in the universal holder shown in Fig. 266.

FIG. 267.



Longitudinal Section of Tubes of Polariscope.

The lens, B, next the object is nearly a hemisphere, about eleven-sixteenths inch in diameter and three-eighths inch focus. The second lens, C, a meniscus (periscopic) spectacle lens of 3 inch focus, is arranged with the concave face one-sixteenth inch from the convex side of the hemisphere. Beyond the 3 inch meniscus, $3\frac{1}{2}$ inches distant, is placed a biconvex spectacle lens, D, of 4 inch focus. The inner surfaces of the tubes are made dead black by the application of a varnish formed of lampblack and alcohol, in which only a trace of shellac has been dissolved.

The tubes may have any suitable diameter, and the proportions of the doubler may be about the same as indicated by Fig. 266, which is one-quarter actual size. The tubes and lenses shown in Fig. 267 are one-half size. The exact proportions, except as to the focal lengths and distances apart of the lenses, are immaterial. The lower system of lenses must produce a very convergent beam of light, while the upper system is

arranged to collect the rays after they pass through the crystal, and bring them within the range of vision.

The angle between the optic axes in some crystals is so small as to permit of seeing them readily. Niter and carbonate of lead are examples of such crystals; but there are other crystals whose angle is so great as to render it exceedingly difficult to exhibit them, and in some crystals the angle is so wide as to render it impossible to see both axes at once. The only method of exhibiting them is by tilting the crystal first in one direction and then in the other, and viewing them separately.

Figs. 268 to 273, inclusive, represent the figures shown by several crystals in the instrument illustrated. The drawings, having been made directly from the objects by the aid of the instrument, are correct in form and proportion, but the beautiful coloring is necessarily absent.

Fig. 268 shows the rings and brushes exhibited by calcite in a convergent beam of polarized light, with the polarizer and analyzer crossed. With the polarizer and analyzer parallel, the dark cross is replaced by a white one.

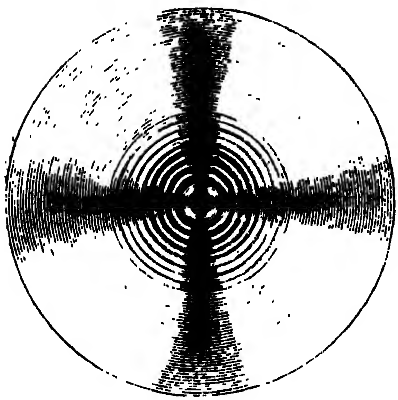
Niter is shown in Fig. 269 as it appears when the analyzer is crossed. With the analyzer parallel with the polarizing plate, the dark brushes are replaced by light ones. Turning the crystal in its own plane produces different effects.

In Fig. 270 is shown a figure produced by a slice of quartz cut at right angles to the axis of the crystal, and examined in the instrument with the analyzer arranged at an angle of 45° with the polarizer. Crystals of quartz vary in their effects on the polarized beam, some requiring the turning of the analyzer to the right and others to the left to produce like results. For this reason the plates are called right or left handed, according to the direction in which the analyzer is required to be turned.

By superposing a right hand quartz on a left hand quartz, the beautiful spirals discovered by Airy, and named after their discoverer, may be exhibited. These spirals are shown in Fig. 271.

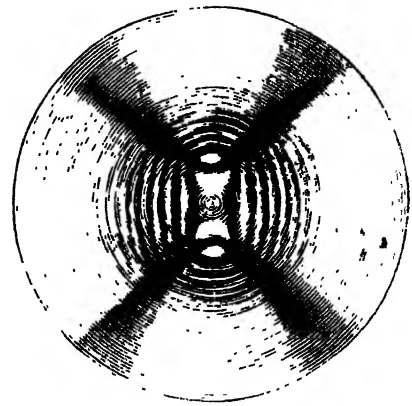
In Fig. 272 is shown the figure produced by the inter-

FIG. 268



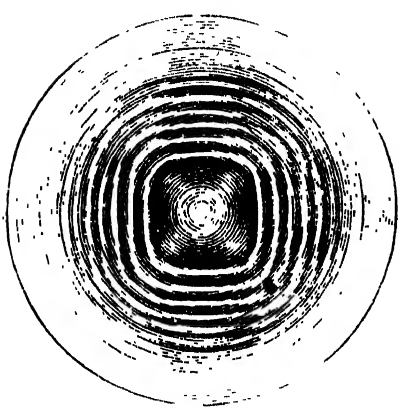
Calcite.

FIG. 269.



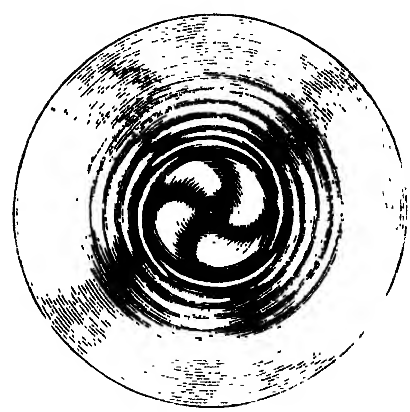
Niter

FIG. 270.



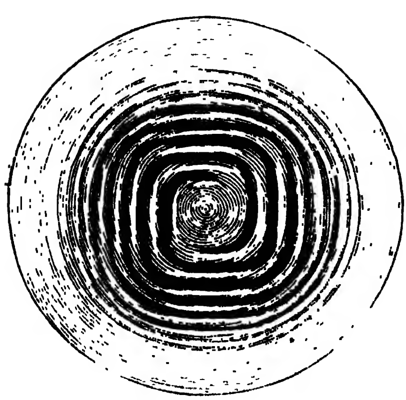
Quartz.

FIG. 271



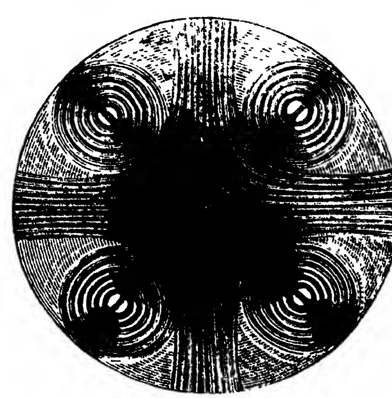
Airy's Spirals.

FIG. 272.



Quartz Polarized Circularly.

FIG. 273

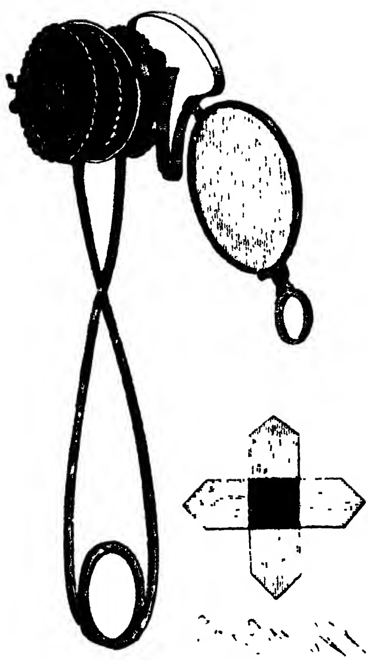


Aragonite Hemitrope.

position of a quarter wave mica film between the polarizer and a plate of quartz viewed in the instrument. This altered appearance is due to circular polarization, a phenomenon treated extensively in the literature of the subject, but requiring an explanation too elaborate for the space at command.

Calcite polarized circularly shows singularly broken up and disjointed rings, the brush-like cross being absent, and when analyzed circularly, or viewed through a quarter wave plate, as well as through the analyzer, the rings appear perfect, and there are no transverse markings.

FIG. 274.



Tourmaline Tongs.

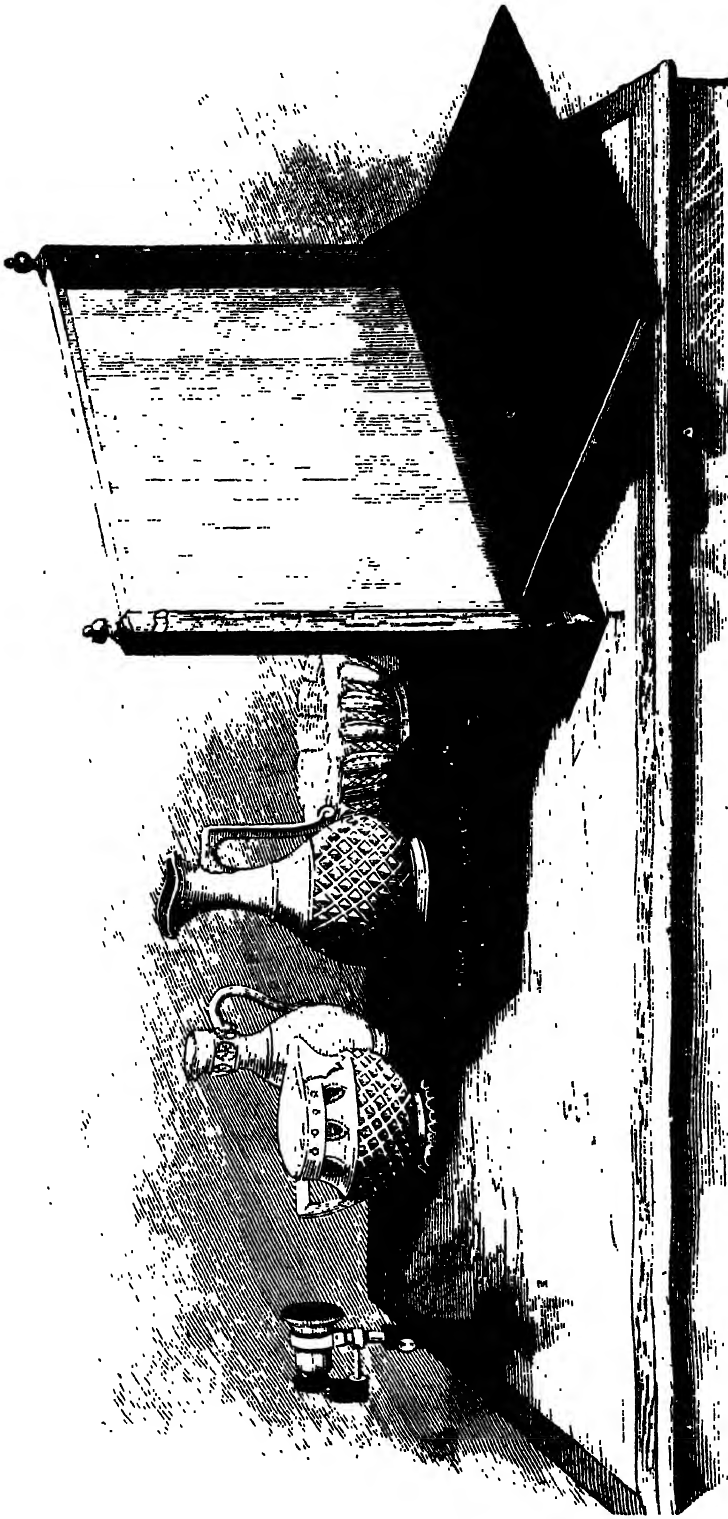
Fig. 273 shows the intricate figure produced by aragonite hemitrope, or a pair of crystals arranged at right angles with each other. Somewhat similar figures are produced by crossed plates of mica.

The following is a list of some additional objects which may be viewed in the instrument:

Sulphate of nickel, sugar, aragonite, bichromate of potash, chrysoberyl, chrysolite, topaz, anhydrite. Instead of employing the Norremberg doubler for polarization, the lower tube may be prolonged, and a large Nicol prism inserted and arranged like the analyzer.

In Fig. 274 is shown the tourmaline tongs, the simplest polariscope known. It consists of two plates of tourmaline, cut parallel to the optic axis of the crystal, and mounted in cells arranged to turn in eyes formed at the extremities of the looped wire. When the plates are parallel, light passes through them; but when they are arranged at right angles with each other, the light is completely extinguished. If a plate of quartz crystal, a Brazilian pebble spectacle lens for

Fig. 275



Polariscope for Large Objects.

example, be placed between the tourmalines arranged in this way, the light will again pass, showing that it has been depolarized by the rock crystal.

This has been accepted as an infallible test of the genuineness of quartz lenses. In the hands of an expert it is undoubtedly valuable, but glass lenses may be put under strain by heating them and allowing them to cool rather quickly. They will then, to some degree, act on the polarized beam like the true crystal.

This form of polariscope is useful in the examination of crystals generally, but on account of the natural dark color of the tourmaline, the utility of the instrument is limited.

In Fig. 275 is shown a polariscope designed for the examination of large objects, such as glassware, etc. It consists of a bundle of 16 glass plates, about 20 or 24 inches square, arranged with reference to the Nicol prism employed as an analyzer at an angle of 35° 25′. Behind the series of plates is hinged a board covered with black velvet, which may be raised up parallel with the glass plates when it is desired to polarize the beam by reflection.

The analyzer, a Nicol prism, is mounted in a revoluble tube, supported by the small adjustable standard. Articles to be examined are placed on the small table between the polarizer and analyzer.

The light for the polariscope should be taken through either a white paper or cloth screen or a plate of ground glass. Any strain in the article examined will exhibit itself by its depolarizing effect on the polarized beam.

SIMPLE POLARISCOPE FOR MICROSCOPIC OBJECTS.

The examination of microscopic crystals by the aid of the polariscope is an exceedingly interesting part of the study of polarized light. The indescribable play of colors, and the variety of exquisite forms of the smaller crystals, render this branch of the subject very fascinating. But to undertake the examination of this class of objects in the usual way requires a microscope with the addition of a polariscope, which calls for an outlay of at least fifty dollars, besides the cost of the objects, and while it is believed that

such an outlay would be indirectly, if not directly, profitable, it is not necessary to expend a fiftieth of that amount to arrive at very satisfactory results.

The cost of the compact and efficient little instrument shown in Fig. 276 is as follows:

One pocket magnifier, having two lenses $1\frac{1}{2}$ inches and 2

FIG. 276.

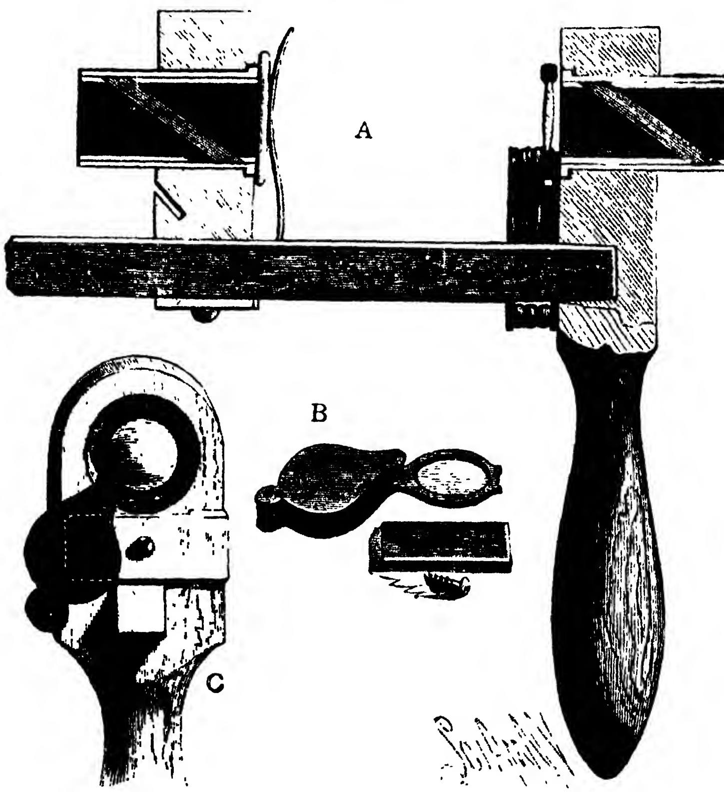
Polariscope for Microscopic Objects.

inches focus respectively, giving when combined a $\frac{3}{4}$ inch focus, 50 cents; eighteen elliptical microscope cover glasses for analyzer, 38 cents. The cost of wood for the principal parts, the pasteboard tubes, the glass for the polarizer, and the metal strips for the slide-holding springs, can hardly be counted, and the labor must be charged to the account of recreation; so that less than one dollar pays for an instru-

ment that will enable its owner to examine almost the entire range of microscopic polariscope objects with a degree of satisfaction little less than that afforded by the use of the best instruments.

The form, proportions, and material of the body of the instrument are entirely matters of individual taste. In the

FIG. 277.



Longitudinal Section of Polariscope and Details. Half Size.
A, Longitudinal Section. B, Magnifier and Clamp. C, Cross Section showing Clamp and Magnifier.

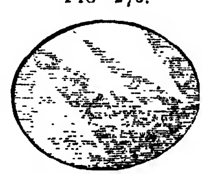
present case, the hand piece and sliding stage are made of ⅜ in. mahogany, the handle being formed on the hand piece by turning. The stage is 2½ in. square, and has in its lower edge a half inch square, transverse groove, which receives the square rod projecting from the hand piece at right angles. The rod is held in the groove by a wooden strip fastened to the lower edge of the stage by two wood

screws, so that it bears with a light friction on the under side of the rod.

The hand piece and stage are both pierced above the rod with holes which are axially in line with each other. The diameter of the holes is governed by the size of the cover glasses. Those in the instrument shown are of the exact size and form of the annexed diagram (Fig. 278).

These cover glasses are procurable from any dealer in supplies for microscopists. Eighteen of them, at least, are required. The paper tube inclosing these glasses is a little more than $\frac{11}{16}$ in. internal diameter; its outside diameter is $\frac{7}{8}$ in. and its length is $1\frac{3}{4}$ in. A narrow paper collar is glued around one end of the tube, and both the hand piece and the stage are counterbored to receive the collar, as shown in the sectional view, A, Fig. 277. To the tube thus described is fitted an internal paper tube, which is about $\frac{1}{8}$ in. shorter than the outer tube. The inner tube is divided diagonally at an angle of 35° 25′, which is the complement of the polarizing angle for glass (54° 35′). The oblique surfaces thus formed, when placed in the tube in opposition to each other, support them between the glass plates at the polarizing angle. The simplest way to arrange the angles of the tubes and other parts of the polariscope is by the employment of a triangle of cardboard like that illustrated in Fig. 279. In fact, a copy of the triangle here shown may be used.

FIG 278.



Elliptical Cover Glass

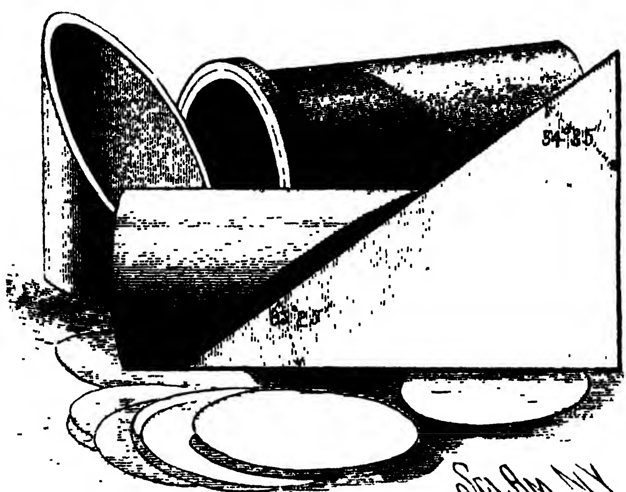
It is sometimes a matter of considerable difficulty to clean the thin cover glasses without the risk of breaking a large percentage of them. An effective device for holding the glasses while they are being cleaned is shown in Fig. 280. It consists of a piece of thin Bristol-board, having an elliptical aperture loosely fitting the edges of the glass to be cleaned, and a plain card glued to the back of the apertured card, and forming the bottom of the shallow recess into which the glasses are dropped for cleaning. The holder may be pressed down upon the table by the fingers of one hand, while the glass is rubbed with a soft linen

handkerchief, after being breathed on. Glasses that cannot be easily and thoroughly cleaned in this way are worthless for this purpose.

Before the glass plates are put together, they are dusted with a camel's hair brush to remove any adhering lint and dust. The paper tubes are made dead black inside and outside.

The front of the stage is provided with a pair of thin brass springs, which serve to clamp the object slide with a light pressure to the stage. In the back of the stage, below the central aperture, is formed a groove for receiving the

Fig. 279.



Triangle and Paper Tube. Full Size.

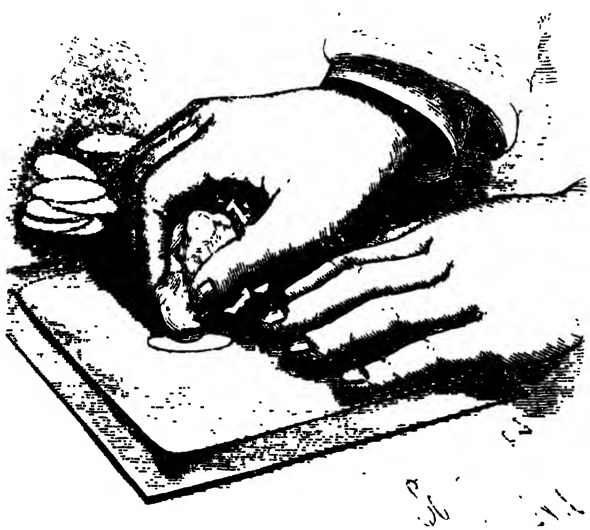
black glass polarizing plate. The groove supports the black glass at an angle of $54^\circ 35'$ with the plane of the stage, or at an angle of $35^\circ 25'$ with the holes in the stage and hand piece. The polarizing plate may consist of a plate of polished black glass, but it is generally more convenient to employ an ordinary piece of glass blackened on one side. A thin pine wedge cemented to the back of the plate causes it to bind in the groove of the stage.

To the inner face of the hand piece is clamped an ordinary pocket magnifier by means of the wooden clip. At C is shown the arrangement of the magnifier relative to the

analyzer. Any convex lens of suitable focus may be pressed into the service. The face of the stage and other parts of the instrument visible through the analyzer are blackened.

The object to be viewed is placed on the stage and focused, when the instrument is held so that the black glass polarizing plate reflects the light through the object and through the analyzer. The analyzer is then turned, and the object observed. To heighten the color effects, a plate of selenite or mica may be placed immediately behind the

FIG. 280



Holder for Glass.

object, or between the stage and black glass plate. Mica plates of suitable thickness are selected by trial in the instrument, and preserved for future use.

It is sometimes desirable to rotate the polarizer. When the black glass plate is used, this is impracticable, but on removing this plate, and inserting in the stage a polarizer consisting of a tube containing plates like the analyzer, the effects of rotating the polarizer may be observed. To render the rotation of the paper tubes smooth and uniform, their bearings in the hand piece and stage are rubbed over with the point of a soft lead pencil, imparting to them a thin

coating of plumbago, which diminishes friction and prevents sticking. The objects which may be examined by the aid of this instrument are very numerous. Many of them are easily prepared, and some need no preparation at all. The chemical salts mentioned below may be prepared for observation by allowing their solutions to evaporate on a slip of glass: Alum, bichromate of potash, bichloride of mercury, boracic acid, carbonate of potash, carbonate of soda, citric acid, chlorate of potash, hyposulphite of soda, iodide of potassium, nitrate of ammonia, nitrate of copper, nitrate of soda, oxalic acid, prussiate of potash (red), prussiate of potash (yellow), sugar, sulphate of copper, sulphate of iron, sulphate of nickel, sulphate of potash, sulphate of soda, sulphate of zinc, tartaric acid.

Slips of glass, 1×3 inches, are convenient for this purpose. A circle about $\frac{3}{4}$ inch diameter is formed on each slip with a piece of paraffin or wax, and while the slips are supported in a level position, a few drops of a rather strong solution are placed in each circle, and the slips are allowed to remain quietly until the crystals form.

For methods of covering and preserving these crystals, as well as for hints on the preparation of the more difficult crystals, the reader is referred to the chapter on microscopy.

The following vegetable and animal substances may be examined by polarized light:

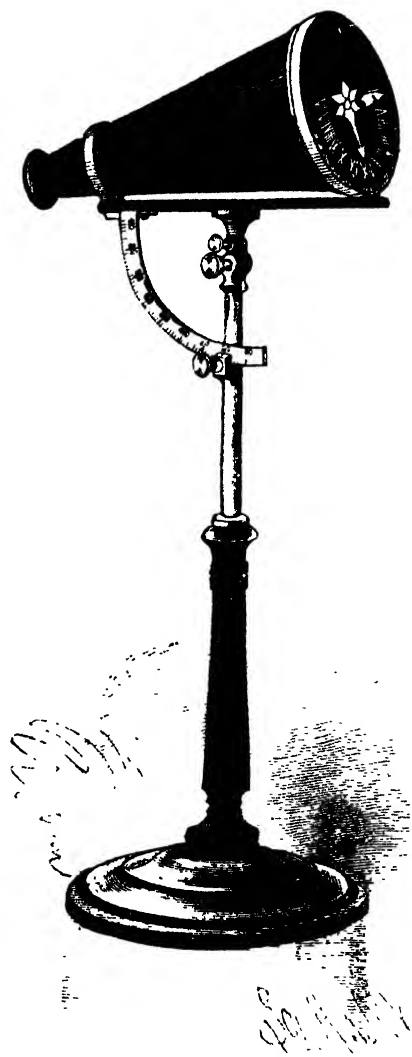
Cuticles, hairs, scales from leaves, fibers of cotton and flax, starch grains, thin longitudinal sections of wood, oiled; spicules of sponges and gorgonia, cuttlefish bone, hairs, quills, horn, finger nail, and skin. These objects should be thin and translucent or transparent. It is necessary in some cases to increase their transparency by soaking them in oil or some other suitable liquid. Many rock sections and sections of minerals may be studied advantageously by the aid of polarized light, but since the object sare quite difficult to prepare, no list of them is given.

PRACTICAL APPLICATIONS OF THE POLARISCOPE.

The practical applications of the polariscope are few but important. In chemistry, its most prominent use is in the

determination of sugars. In medicine, it finds an application in the examination of diabetic urine. In geology and mineralogy, it is of utility in determining the origin and nature of rocks and minerals. In photometry, it forms the basis of several photometers. In photography, the polariscope, or at least a part of it—the Nicol prism—has been employed for reducing the glare of highly illuminated objects. In a similar way, the Nicol prism has been used for extending the field of vision in a fog. It forms an important part of the water telescope. It has also been used to some advantage in viewing paintings unfavorably situated in galleries. In the trades the polariscope has proved useful in detecting strains in glass. By opticians, it has for years been recognized as a test for the genuineness of Brazilian pebble lenses for spectacles. It has also proved of great utility to the microscopist in the examination of minute structures.

Fig. 281.



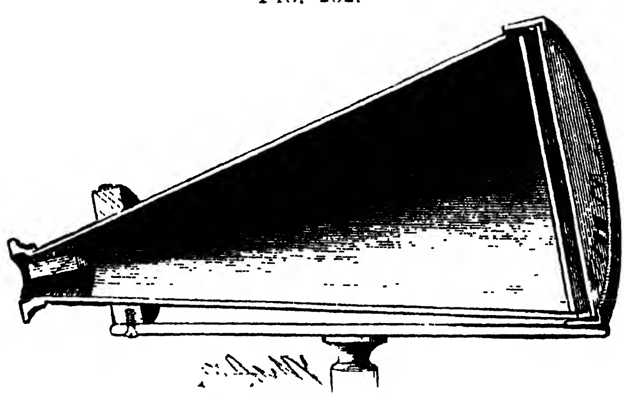
Wheatstone's Polar Clock.

The polariscope has recently been applied in France to determining the temperature of incandescent iron and other metals. The color of a glowing mass of metal varies according to its temperature, and a ray of the light when polarized is rotated by a plate of quartz to a degree dependent upon the color. The degree of rotation is measured by the polariscope, and an empirical scale of temperature

is thus obtained, which has been found very useful and reliable in metallurgical operations.

One of the most curious uses of polarized light is the indication of the time of day. Sir Charles Wheatstone devised a polar clock in which a Nicol prism in connection with atmospheric polarization is made to indicate the time of day. Several forms of this instrument have been made; one of them is shown in Figs. 281 and 282.* Atmospheric polarization, according to Professor Tyndall, is due to the reflection of light from the fine particles of matter floating in the air. By examining the sky on a clear day by means of a Nicol prism and a plate of selenite or

FIG. 282.



Longitudinal Section of Polar Clock.

other crystal, polarization will be detected without difficulty. The brightest effects are noticed at a point 90° from the sun. By directing a Nicol prism to the north pole of the heavens —a position always at right angles to the sun, or approximately so—and turning it round, the colors of the crystal plate, viewed through the prism, will change in a definite order, or, if the position of the Nicol be fixed, the movement of the sun will produce similar changes of color. The polar clock is based upon this principle.

The inventor describes this instrument as follows: "At the extremity of a vertical pillar is fixed, within a brass ring, a glass disk, so inclined that its plane is perpendicular to the

* Other forms are described in Spottiswoode's "Polarization of Light."

polar axis of the earth. On the lower half of this disk is a graduated semicircle, divided into twelve parts (each of which is again subdivided into five or ten parts), and against the divisions the hours of the day are marked, commencing and terminating with VI. Within the fixed brass ring containing the glass dial plate, the broad end of the conical tube is so fitted that it freely moves round its own axis; this broad end is closed by another glass disk, in the center of which is a small star or other figure, formed of thin films of selenite, exhibiting, when examined with polarized light, strongly contrasted colors: and a hand is painted in such a position as to be a prolongation of one of the principal sections of the crystalline films. At the smaller end of the conical tube a Nicol prism is fixed so that either of its diagonals shall be 45° from the principal section of the selenite films.

The instrument being so fixed that the axis of the conical tube shall coincide with the polar axis of the earth, and the eye of the observer being placed to the Nicol prism, it will be remarked that the selenite star will in general be richly colored; but as the tube is turned on its axis the colors will vary in intensity, and in two positions will entirely disappear. In one of these positions, a smaller circular disk in the center of the star will be a certain color (red for instance), while in the other position it will exhibit the complementary color.

This effect is obtained by placing the principal section of the small central disk 22½° from that of the other films of selenite which form the star. The rule to ascertain the time by this instrument is as follows: The tube must be turned round by the hand of the observer until the colored star entirely disappears, while the disk in the center remains red; the hand will then point accurately to the hour.

"The accuracy with which the solar time may be indicated by this means will depend on the exactness with which the plane of polarization can be determined. One degree of change in the plane corresponds with four minutes of solar time."

SUGGESTIONS IN DECORATIVE ART.

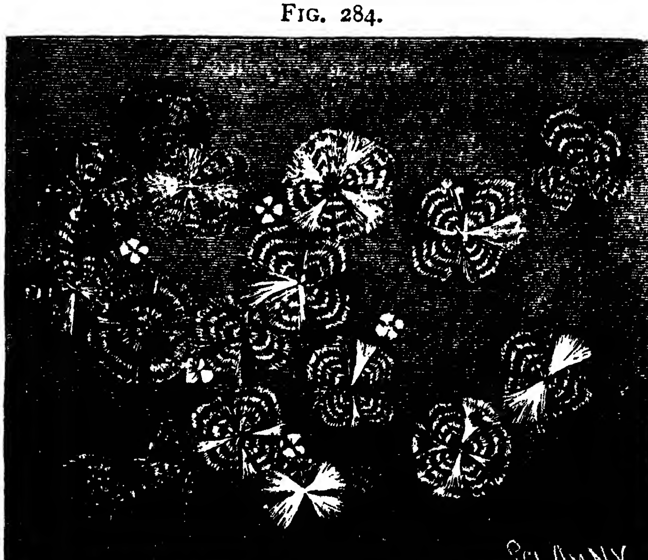
Occasionally, evidences of the use of the microscope in decorative art are seen, and every microscopist knows that

FIG. 283.

Salicine Crystals.

there are thousands of beautiful forms lost to unaided human vision which are revealed only to the user of the

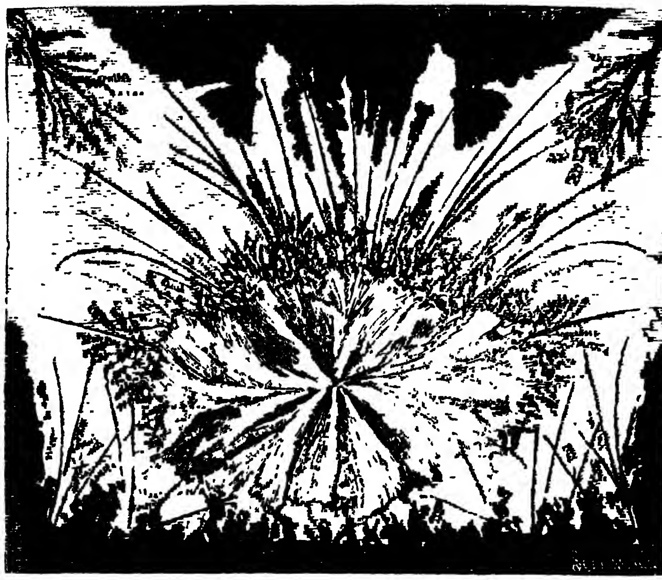
FIG. 284.



Sulphate of Cadmium.

microscope.* These minute forms are always exquisite in their construction and finish, often symmetrical and graceful

FIG. 285.



Santonine.

in form, and quite as often finely colored. All this is true of microscopic objects in general, but it is especially true of

FIG. 286.

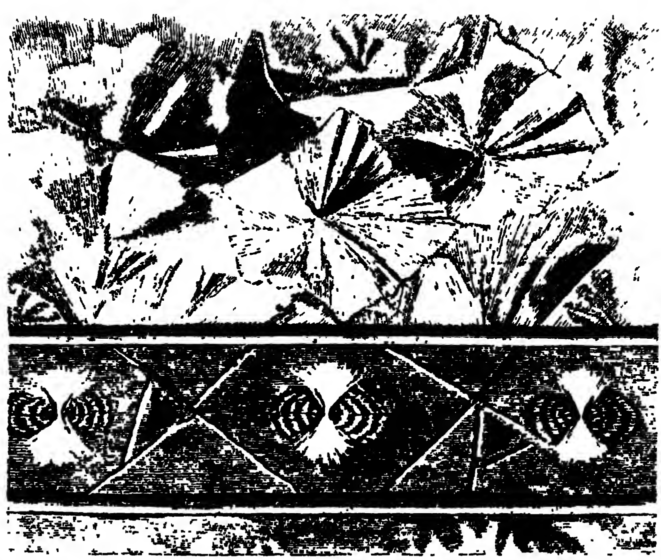
Lithic Acid.

* See also chapter on microscopy.

polariscopic microscope objects. Some of these are, to a certain extent, artificial. The crystals, for example, are the result of manipulation, but the laws of crystallization are natural, so that, after all, we are indebted to nature even for these objects.

In the present instance, a few striking examples of crystallization have been selected as the basis of some suggestions in decorative art. These crystals, as exhibited by polarized light in the microscope, are shown in the annexed engravings, necessarily divested of their principal charm—

FIG. 287.



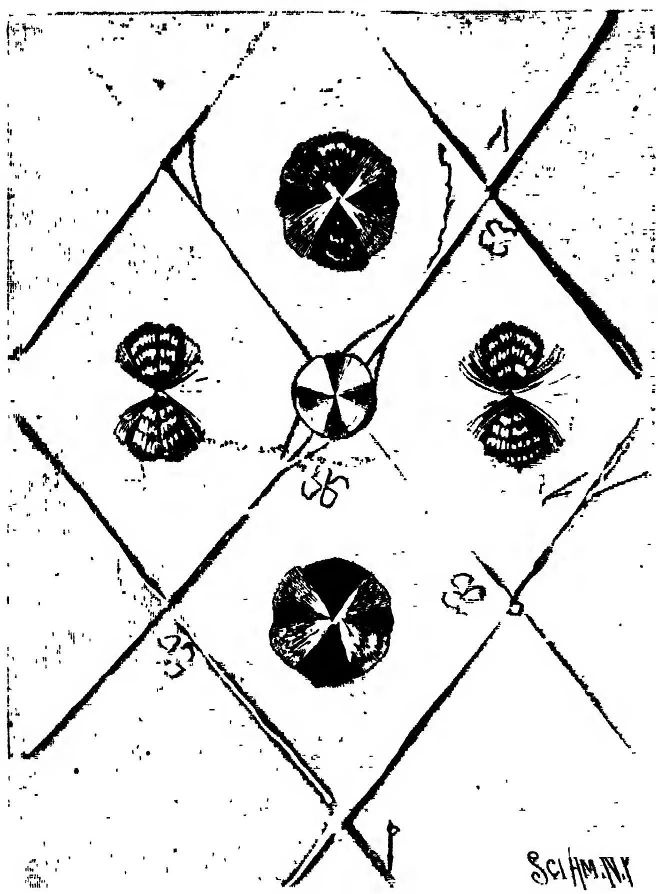
Border Dado or Frieze.

that of color. The forms only are shown. The reader can imagine these figures invested with most gorgeous colors combined in a perfectly harmonious way. In respect to color, the polariscope never errs. Whatever colors are presented are correctly related to each other. This feature alone is of great value to the designer and colorist. The circular crystals of salicine, shown in Fig. 283, are always interesting. The play of the radial bands of color as the polarizer or analyzer is revolved gives each disk the appearance of having an actual rotation of its own.

In Fig. 284 are shown the delicate, feathery crystals of sulphate of cadmium, in which the coloring, as exhibited by polarized light, is scarcely more beautiful than the exquisite forms. The shapes of the different crystals vary somewhat, but there is a characteristic feature pervading them all.

In Fig. 285 are shown crystals of santonine in a variety

FIG. 288.



Panel with Ornamentation of Crystals.

of forms—some like spears of grass, others resembling heads of grain, and still others like ferns and various leaves, while the larger crystals or aggregation of crystals has a radial arrangement.

In Fig. 286 are shown crystals of lithic acid, which adjoin each other, and form a solid field, having strongly contrasting bands of light and dark color.

Fig. 287 will be recognized as a part of a dado, frieze, or border, formed of lithic acid as a ground, crystals of platino-cyanide of barium as the division of the panels, and crystals of sulphate of cadmium as rosettes upon the centers of the panels.

Fig. 288 shows a panel formed in part of the same crys-

FIG. 289.

A Composite Border.

tals, with a crystal of salicine planted at the intersection of two of the slender platino-cyanide of barium crystals, and small crystals of kinate of quinia forming flowers.

In Fig. 289 is shown a border formed of crystals of santonine, arranged on a ground of neutral tint, with a row of circular crystals of sulphate of copper and magnesia above

a row of crystals of kinate of quinia, arranged on a dark ground.

Fig. 290 shows a pattern having a background of stearic

FIG. 290.

Pattern with Background of Stearic Acid and Crystal Leaves, Stalks, and Flowers.

acid, branches of platino-cyanide of barium, leaves of platino-cyanide of magnesium, and flowers of salicine.

What has been shown in the engravings constitutes only a hint of what may be done in this direction. The number of beautiful crystals and other polariscope objects available for this purpose is very large.

CHAPTER XIII.

MICROSCOPY.

The world of the minute existing beyond the range of the unaided vision is little realized by those who take no interest in microscopy. The beauty and perfection of the smaller works of nature can never be fully known through the medium of literature or art; the objects themselves must be observed by the student personally.

In every pond and stream may be found microscopic forms of life. In every plant and flower, upon leaves and stalks, among the sands and rocks, almost everywhere in all seasons, may be found objects of absorbing interest to the student of microscopy. Animals and insects, food and manufactured articles, yield objects which may be examined microscopically with pleasure and profit. Chemistry and mineralogy afford attractive fields, and the physicist finds the microscope a necessity in his investigations. In fact, one so inclined cannot fail of finding interesting and instructive objects with little difficulty.

Microscopical investigations may be carried on by the aid of an ordinary inexpensive microscope, but this, in the natural course of things, will give place to a more perfect instrument and a complete list of accessories, provided the student becomes interested in the subject. A fine instrument is desirable on account of its wider range of usefulness, its superior optical powers, and the facility with which it may be adapted to different classes of objects. It has the further important advantage of being less fatiguing to the eyes.

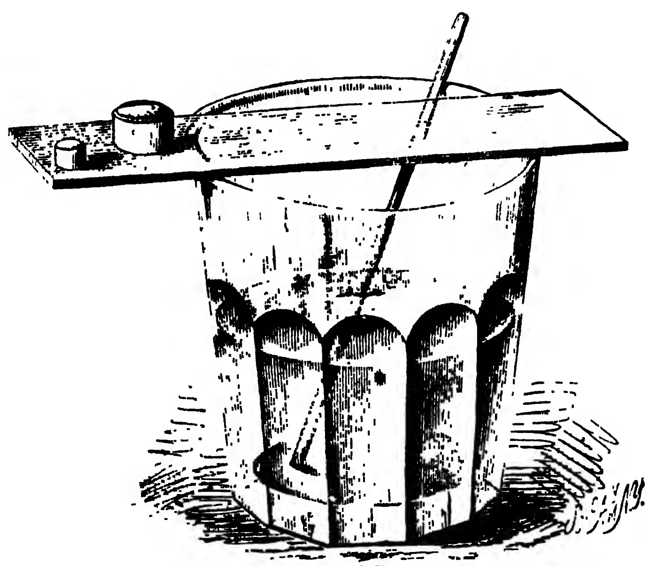
The simplest and cheapest of all microscopes is represented in Fig. 291. It consists of a thin piece of glass, having attached to it one or two short paper tubes, which are coated with black sealing wax, and cemented to the glass with the same material.

By aid of the small stick water is placed, drop by drop, in the cells until the lenses acquire the desired convexity. Objects held below the glass will be more or less magnified, according to the diameter and convexity of the drop.

A convenient stand for the water lens is shown in Fig. 292. The detail views are vertical sections of the lenses, showing the screw for adjusting the convexity of the drop.

The stand is made of wood. The sleeve that supports the stage slides freely upon the vertical standard. A wire having a milled head passes through the upper end of the

FIG. 291.



Simple Water Lens Microscope.

standard, and has wound upon it a strong silk thread, one end of which is tied to a pin projecting from the stage-supporting sleeve. An elastic rubber band is attached to the lower end of the sleeve, and to a pin projecting from the standard near the base, to draw the table downward. The stage is raised or lowered by turning the milled head.

Two standards project from the bed piece for receiving the corners of a rectangular piece of silvered glass which forms the reflector.

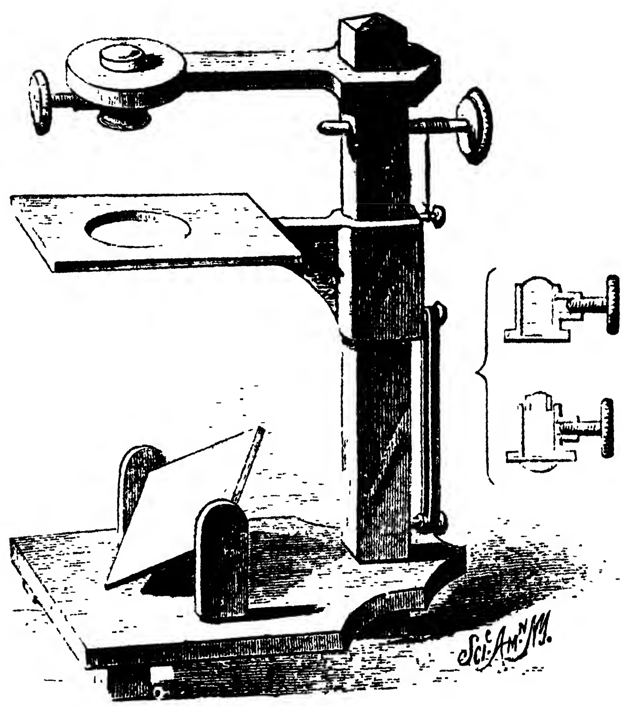
The water cell consists of a brass tube about $\frac{3}{8}$ inch long and $\frac{1}{8}$ to $\frac{3}{16}$ inch internal diameter, having in one side

a screw for displacing the water to render the lens more or less convex. A thin piece of glass is cemented to the lower end of the tube, and the inside of the tube is blackened.

Several bushings may be fitted to the upper end of the tube to reduce the diameter of the drop, and thus increase the magnifying power of the lens.

Water containing animalcules or a solution of a salt for crystallization may be placed on the under surface of the

FIG. 292



Water Lens Microscope Complete.

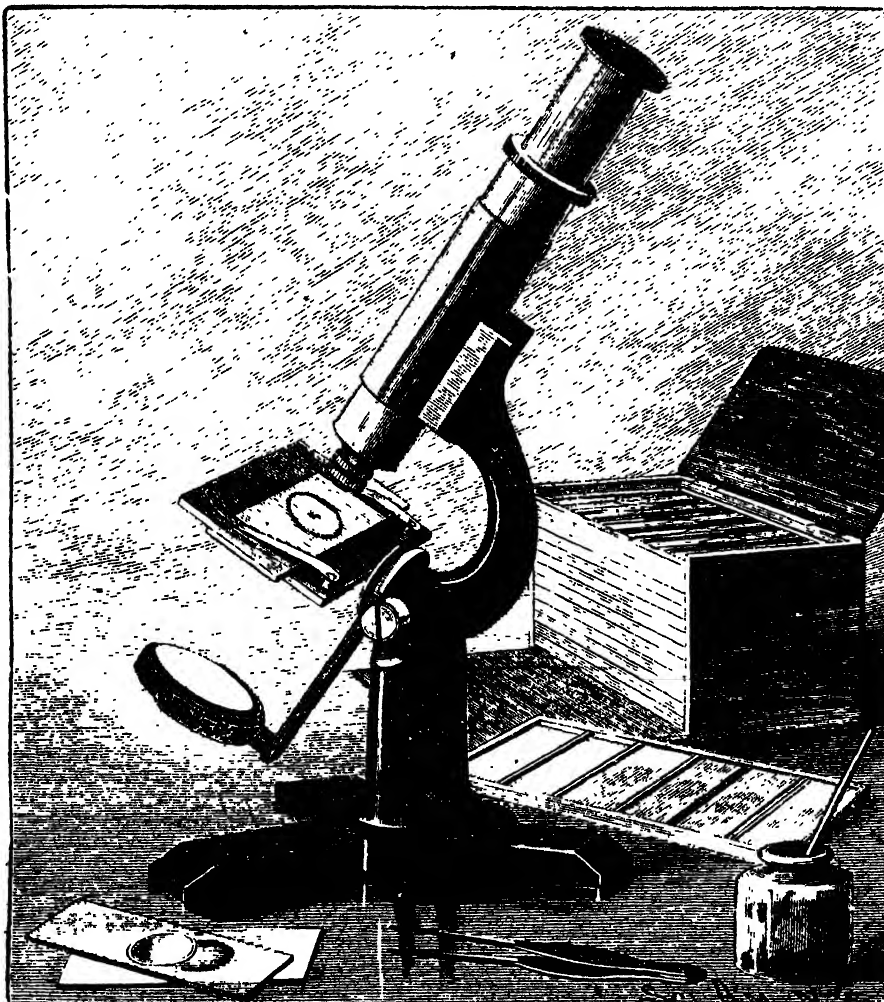
glass, when the lens may be focused by turning the adjusting screw. The lens may be adjusted to magnify objects placed on the movable stage by rendering it less convex, thus increasing its focal length.

Air bubbles forming on the upper surface of the glass may be readily displaced by means of a cambric needle.

The water lens microscope or any lens or combination of lenses through which an erect virtual image is seen, magnified, is known as a simple microscope, while a compound

microscope is an instrument in which a lens, or system of lenses, known as an objective, forms a real and greatly enlarged image of the object, and in which this image is itself magnified by a second lens or system of lenses, known as the eyepiece or ocular.

FIG. 293.

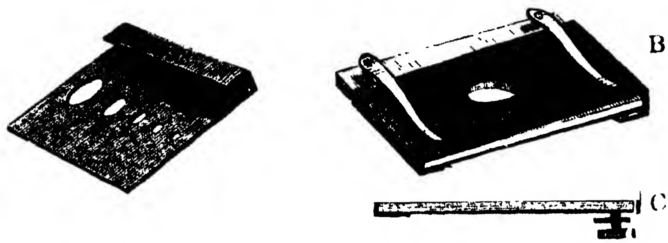


Compound Microscope.

An inexpensive compound microscope is shown in Fig. 293. This instrument, when closed, is 8 inches high, and has a draw tube which permits of extending it to a height of 11 inches. The foot and arm are of japanned iron. The tubes are well finished and lacquered. It has an

achromatic objective divisible into two powers. The mirror may be swung over the stage for the illumination of opaque objects.

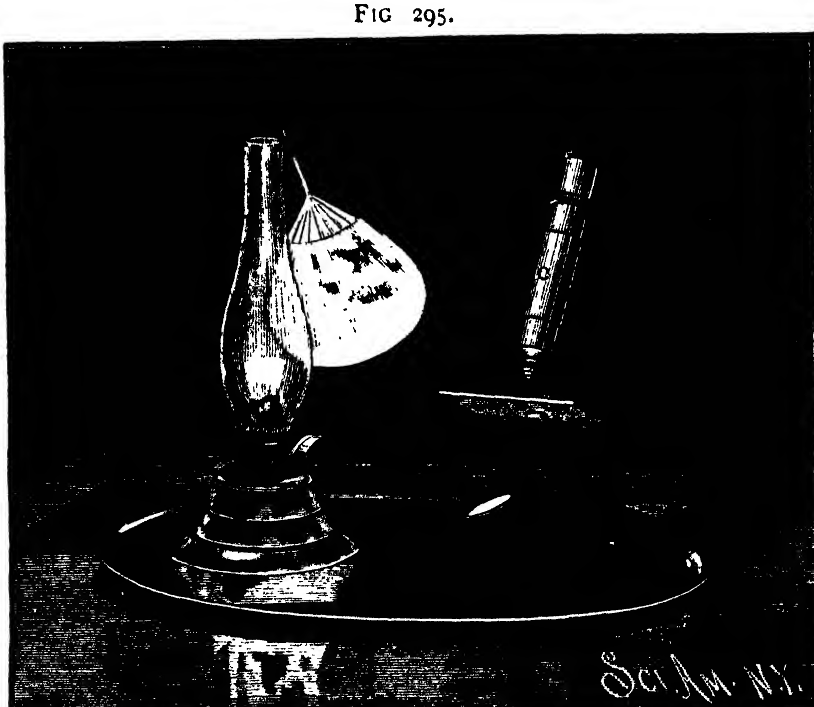
FIG. 294.



Diaphragm and Fine Adjustment.

To the instrument as received from the manufacturer is applied a home-made diaphragm, as shown at A, in Fig. 294, and a fine adjustment, as shown at B C, in the same fig-

FIG 295.



Substitute for Revolving Table.

ure. The diaphragm consists of a piece of perforated thin sheet metal, extending along the under surface of the stage, and neatly bent over the outer edge of the stage, so as to be

self-supporting—the perforations of the metal being respectively one-sixteenth, one-eighth, three-sixteenths, one-fourth, and five-sixteenths inch diameter, all arranged on a longitudinal line of the metal plate intersecting the axial line of the microscope tube, so that the centers of the holes of the diaphragm may be made to coincide with the center of the hole in the stage.

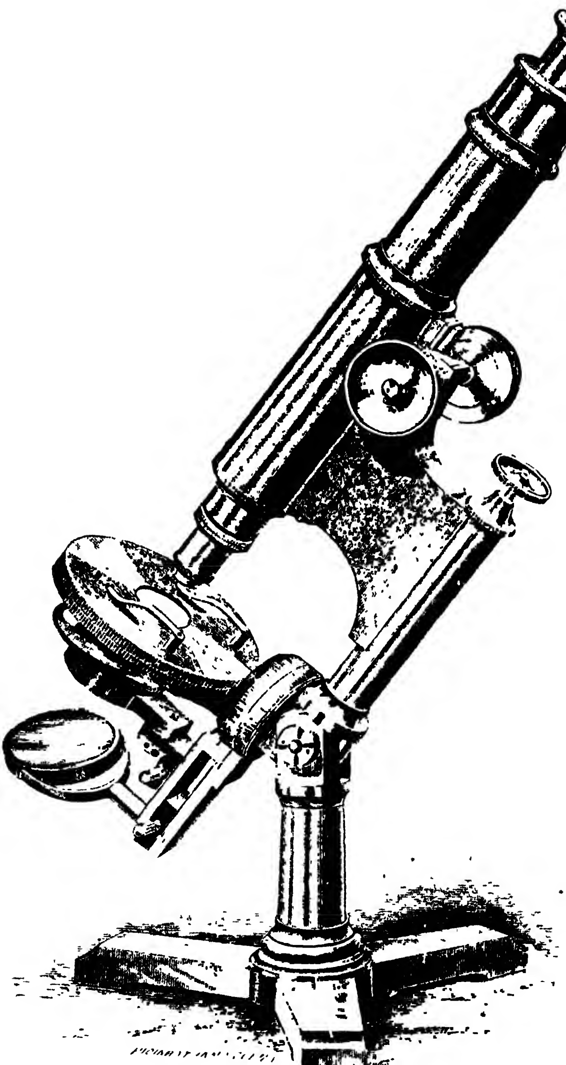
The attachment for fine adjustment is made by bending one end of a thin metal plate twice at right angles, so that it will spring on the edge of the stage and clamp the stage tightly. The opposite end of the metal plate is bent in a similar manner, but the space between the body of the plate and the bent-over end is made wider, to permit of a small amount of movement of this end of the plate. In the portion of this end of the plate extending under the stage is inserted a fine screw with a milled head, by means of which the free end of the plate may be made to move either up or down through a small distance. The body of the plate is inserted under the stage clips, and the object slide is inserted between the clips and the movable plate.

The instrument has no rack adjustment, but the main tube slides easily and smoothly in the guide tube, so that little or no difficulty is experienced in focusing. Besides the instrument and accessories, only the following articles will be required to begin in earnest the study of microscopic objects: A small pair of spring forceps, a bottle for objects, a few concaved glass slides, a few thin cover glasses, a glass drop tube, a small kerosene lamp; and if the investigator desires to entertain his friends with the microscope, he will need a Japanese or tin tray, large enough to contain both microscope and lamp, as shown in Fig. 295, so that the relation of both may be preserved while the tray is moved to bring the instrument into position for different observers, by simply sliding the tray on the table.

A little caution as to illumination is necessary, as the beginner is generally unsparing of his eyes, using far too much light. A blue glass screen placed between the mirror and source of light, or between the mirror and the stage, modifies the light so as to greatly relieve the eyes.

The lamp should be provided with a shade of some sort to prevent the light from passing directly from the lamp to the eyes. A small Japanese fan suspended from the chim-

FIG. 296.



A Modern Microscope.*

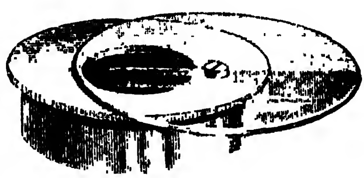
ney by a wire, as shown, forms a very desirable shade. Most objects viewed by transmitted light in an instrument of this class require an absolutely central light, that is,

* Bausch & Lomb Optical Co.'s "Universal."

the light must be reflected straight upward through the object and through the tube.

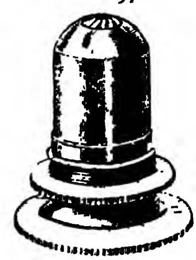
When opaque objects are examined, the mirror is raised above the stage and made to concentrate the light on the object. Different angles of illumination should be tried, as some objects are greatly relieved by their shadows, while

FIG. 297.



Light Modifier.

FIG. 297*a*.

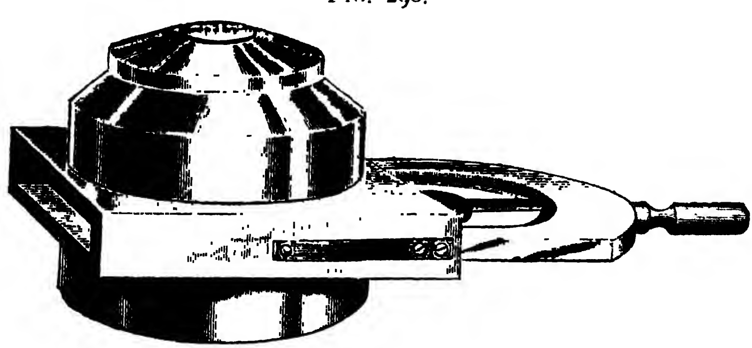


Iris Diaphragm.

others require illumination as nearly vertical as possible. Experience will soon indicate the right magnification for different objects. This may be varied by taking off or putting on the lower half of the objective, also by drawing out or pushing in the draw tube.

For truly scientific microscopical work a better instru-

FIG. 298.



Sub Stage Condenser.

ment than that already described will be needed. The microscope shown in Fig. 296 is perfectly adapted for general use. The main tube has two draw tubes by which any desired tube length may be secured. The coarse adjustment is effected by means of a rack and pinion; and a

micrometer screw is used for the fine adjustment. The stage, which is revoluble, is made thin to allow of the greatest obliquity of illumination. The arms which support the sub-stage and the mirror turn upon the same axis, and are capable of being moved independently. The mirror may be swung above the stage for the illumination of opaque objects.

The sub-stage is adapted to receive any of the accessories, such as the light modifier shown in Fig. 297, the condenser represented in Fig. 298, and other desirable and indispensable appliances. A stand of this character is perfectly adapted to objectives of the highest class. All adjustments required to secure any angle of illumination, any position of the object, or any degree of fineness of focalizing, can be made quickly and with precision. The possessor of a microscope of this quality will always feel a degree of satisfaction which the poorer instrument can never give.

A larger, more complete, and at the same time much more expensive microscope is shown in Fig. 304, in connection with light-intermitting apparatus. This microscope has, in addition to the features already described, complete mechanism for centering the stages, a rack and pinion for the sub-stage adjustment, a graduated circle on the stage, a graduated head on the micrometer screw, graduations upon the pillars for the angle of inclination of the tube, and graduations at the base for measuring angles of objectives. A microscope of either of these grades, with a complement of fine objectives, eyepieces, and other necessary accessories, will yield all the results attainable at this stage of microscopy.

The graduated blue glass light modifier above referred to consists of a disk of flashed glass ground and polished so as to give all shades between white and dark blue, both transparent and translucent. This disk is pivoted upon an adapter (Fig. 297), so that it may be turned to receive any desired quality of illumination. It may be used in conjunction with the condenser shown in Fig. 298. This condenser is fitted to the sub-stage, and is provided with several stops

and diaphragms, by which the light may be controlled. This condenser has a very wide angle, and is adapted for use in connection with objectives of all grades; but its efficiency is specially noticeable when it is used in connection with objectives of high numerical aperture in the examination of difficult objects and the resolution of tests.

The iris diaphragm shown in Fig. 297*a* is of great value in ordinary work. As its name indicates, its aperture may be expanded or contracted to adapt it to a particular object. It shuts off much superfluous light, thus saving the eyes; at the same time improving definition of the object.

For further information regarding microscopes and their accessories the reader in referred to the literature of the subject. Of this there is an ample supply.*

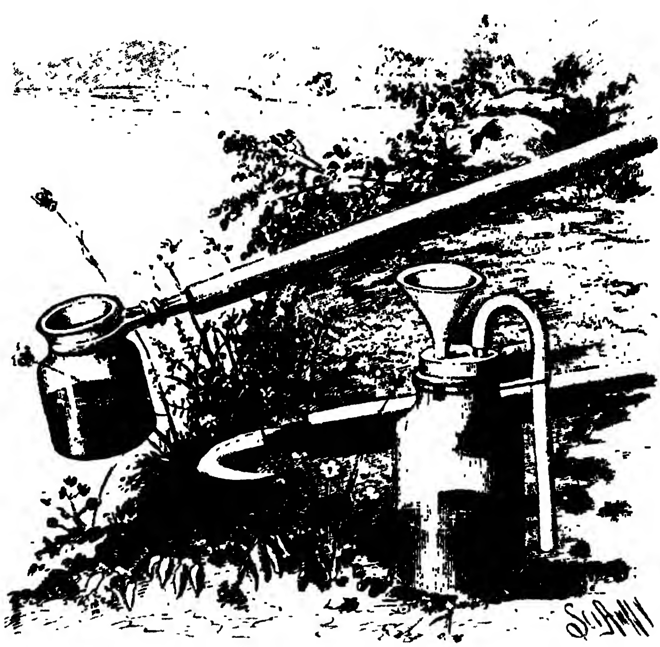
GATHERING MICROSCOPIC OBJECTS.

Objects for microscopical examination are gathered by means of a wide-mouthed bottle clamped in tongs attached to a long handle, cane, or even a fishing rod. By this device mud can be removed from the bottom, the stems and leaves of aquatic plants can be scraped so as to remove animalcules, and objects can be readily dipped from pools and shallow places. The under surface of plants and of grasses hanging over into the water may be scraped with the bottle, and more or less of the matter adhering thereto will be secured. Occasionally a long leaf like that of the flag may be lifted from the water and traversed by the bottle with good results. Small twigs and dead leaves floating in the water are often found teeming with life. The thousands of animalcules and forms of minute plant life found in water will afford the most zealous student a life-long supply of objects for examination. A wide-mouthed bottle or jar is provided with a perforated cork, in which is inserted a funnel for receiving the material; and another funnel, inverted and placed within the jar or bottle, with its nozzle extending

* "The Microscope and its Revelations," by Carpenter; "How to Work with a Microscope," Beale; "How to See with a Microscope," Smith; and "Practical Microscopy," by George E. Davis, are among the excellent works on the subject.

upward through the stopper, is used for concentrating the material. Over the lower end of this funnel is stretched a piece of thin muslin, and to the upper end is applied a short piece of rubber pipe, which is retained in a curved position by a thread tied around the neck of the bottle. The material gathered is poured into the funnel, the water escapes through the strainer, and the objects are retained in the bottle.* The hooked knife shown in the engraving is of great

Fig. 299.



Implements for gathering Microscopic Objects.

utility in cutting and fishing out parts of aquatic plants and submerged branches and roots, which are often teeming with microscopic life.

It would be futile to attempt anything more than the mere mention of a few of the interesting objects that may be seen to advantage in a small microscope. In Fig. 300 the engraver has beautifully shown some of the common objects which are easily secured, readily examined, and always interesting.

* This device is due to Mr. Stephen Helm.

FIG. 300.

1. Seeds. 2. Tongue of Fly. 3. Bee's Wing. 4. Deutzia Leaf. 5. Diatoms and Desmids. 6. Entomostraca. 7. Infusoria Rotatoria. 8. Foraminifera. 9. Spicules. 10. Spicules and Plates. 11. Pollen of Marsh Mallow. 12. Plant Hairs. 13. Shepardia Canadensis. 14. Crystals of Silver. 15. Fern Gold. 16. Gathering Objects.

Various Microscopic Objects.

At 1 in this engraving are shown various seeds; the lace-covered one at the top being the seed of the *Nemesia compacta*. The seed in the center is that of heather. That on the right of the lace-covered one is the seed of the poppy. The fringed one below it is that of the climber. At the bottom of the disk the seed of sorrel is shown at the left, and portulacca at the right. The remaining seed at the left is that of eucharidium.

No. 2 represents the proboscis of the blowfly as it appears in the field of the microscope, except that the intricate structure of the pseudo-trachea is not shown in the cut as it appears in the microscope.

No. 3 shows the doubling hooks of a bee's wing, which enable the insect to connect the wings of each pair so that they may be used as a single wing.

No. 4 shows the silicious stellate hairs on the back of a deutzia leaf. The upper half of 5 shows several forms of diatoms, and the lower half is filled with desmids.

In 6 branchipus is shown at the top, cyclops at the left, a young cyclops at the bottom, and daphnia or the water flea at the right. These are common in almost every pond.

In disk 7 are shown on the left the stentor, so named on account of its trumpet-like form; in the center the beautiful and sensitive vorticella, and upon the right of the vorticella common rotifer, and upon the extreme right the sheathed trumpet animalcule. All of these have cilia around their margins, which by their peculiar vibratory motion give the bell-shaped mouths the appearance of rotation. In the common rotifer, and in the animals shown in disk 6, the internal organs may be readily seen in operation.

In the upper part of disk 7 are shown a few of the hundreds of forms of life found in water in which animal or vegetable matter has been infused.

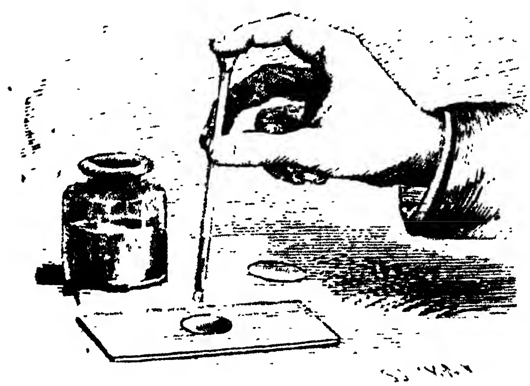
In disk 8 are represented a number of the exquisite little shells of foraminifera. At 9 are shown various spicules of sponges, sea urchins, etc. At 10 are shown sponge spicules and the anchor of *Synapia inhærens;* 11 shows the pollen of marshmallow, and 12 and 13 are examples of plant hairs;

14 shows arborescent crystals of silver, and 15 the crystals of gold.*

TRANSFER OF OBJECTS TO SLIDE.

The objects are transferred from the bottle to the concavity of the slide for examination in the manner shown in

FIG 301.



Transferring Objects to the Slide.

Fig. 301. The drop tube, which has a funnel-shaped top, is stopped by the finger at the upper end, while its lower end is inserted in the water in the bottle above the matter to be removed. The finger is then removed and some of the

FIG. 302

Compressor.

water, together with the objects carried by it, rushes upward into the tube. While the lower end is still in the water, the finger is again placed on the tube and this is withdrawn from the bottle and held over the cavity of the

* The following books are recommended to the beginner in microscopy: Wood's "Common Objects for the Microscope;" "One Thousand Objects for the Microscope," by M. C. Cooke; "Evenings at the Microscope," by Gosse; and "Practical Microscopy," by George E Davis

slide, as shown in the engraving, when a drop or so of the water is forced out by pressing down the end of the finger on the top of the tube; the soft end of the finger acting as a sort of diaphragm in forcing out the required amount of water. Care must be taken to avoid getting solid matter upon the slide around the edge of the cavity, as it will prevent the cover glass from seating itself properly. The cover glass is placed over the cavity and pressed down lightly to squeeze out the surplus water, when the slide may be inserted under the clips of the stage and examined.

A more convenient device for holding animalcules is represented in Fig. 302. It is known as the compressor, and serves to lightly hold any object placed between the glass in the oblong plate and the glass in the adjustable arm. In any position it retains a drop of water.

To confine living objects to the field of vision, it is common to place between the glasses of the compressor a few fibers of cotton or a piece of fine lace.

MICROSCOPIC EXAMINATION OF CILIATED ORGANISMS BY INTERMITTENT LIGHT.

Every observing person has noticed that moving objects appear stationary when viewed by a flash of light; examples of this are seen during every thunder storm occurring in the night. The wheels of a carriage, a moving animal, or any moving thing, seen by the light of the lightning, appears perfectly stationary, the duration of the light being so brief as to admit of only an inappreciable movement of the body while illumination lasts.

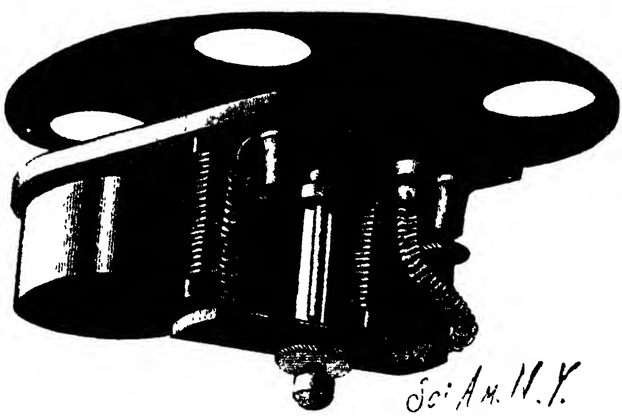
If by any means a regular succession of light flashes be produced, the moving body will be seen in as many different positions as there are flashes of light. If a body rotating rapidly on a fixed axis be viewed by light flashes occurring once during each revolution of the body, only one image will be observed, and this will result from a succession of impressions upon the retina, which by the persistence of vision become blended into one continuous image. In this case no movement of the body will be apparent, but if the

flashes of light succeed each other ever so little slower than the rotary period of the revolving body, the body will appear to move slowly forward, while in reality it is moving rapidly; and should the light flashes succeed each other more rapidly than the revolutions of the revolving body, the body will appear to move slowly backward, or in a direction opposite to that in which it is really turning.

These curious effects are also produced when the number of the light flashes is a multiple of the number of revolutions, or *vice versa*.

The combined effect of interrupted illumination and persistence of vision may be practically utilized for examining objects under motion which could not otherwise be satis-

FIG. 303



Sci Am. N.Y.

Light Interrupter for the Microscope.

factorily studied. To apply intermittent light to the microscopical examination of ciliated organisms, the writer has devised the electrically rotated apertured disk shown in Fig. 303, which is arranged to interrupt the beam of light employed in illuminating the object to be examined.

The instrument consists of an electric motor of the simplest kind mounted on a plate having a collar fitted to the